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MINISTRY OF SUPPLY

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT

FELIXSTOWE

INVESTIGATION OF HIGH LENGTH/BEAM RATIO SEAPLANE HULLS WITH HIGH BEAM LOADINGS

HYDRODYNAMIC STABILITY PART 7

THE STABILITY AND SPRAY CHARACTERISTICS OF MODEL D

by

J.K. FRISWELL, B.Sc.

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November 1953

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT, FELIXSTOWE, SUFFOLK.

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S U M M A R Y

In this report results are presented of tests on the hydrodynamic characteristics of model D of the series. This model has a length to beam ratio of 10 (the forebody being 6 beams in length and the afterbody 4 beams), no forebody warp, an afterbody to forebody keel angle of 6°, and a straight transverse step with a step depth of 0.15 beams.

The tests comprised the determination of longitudinal stability limits without slipstream at $C_{\Delta o}$ = 2.25 and 2.75, an investigation of spray at these loadings, and an assessment of directional stability. A short discussion of the results is also included.

Addendum to M.A.E.E. Report No. F/Res/241

Figure 11 should be disregarded, as subsequent measurements have shown the formula used to be somewhat inaccurate.

/ LIST OF CONTENTS

LIST OF CONTENTS

LIST OF TABLES

/ LIST OF FIGURES

LIST OF FIGURES

1. INTRODUCTION

In this report results are given of tests on the stability and spray characteristics of model D of the series detailed in Reference 1, a list of which is reproduced in Table I. Full details are given in this reference of the considerations affecting the design of the models, but it may be mentioned here that model D has a length to beam ratio of 10 (the forebody being 6 beams in length and the afterbody 4 beams), no forebody warp, an afterbody to forebody keel angle of 6°, and a straight transverse step with a step depth of 0.15 beams. Figure 1 gives the hull lines of the model and Figure 2 photographs of it. Full hydrodynamic and aerodynamic data relevant to this model are given in Tables II and III. The techniques used in the tests and the presentation of results, together with the reasons for using them, are considered in References 1 and 2, though a brief summary is given in the next section.

The tests performed included the determination of longitudinal stability limits at $C_{\Delta_o} = 2.25$ and 2.75 without slipstream, of the spray characteristics at these values of C_{Δ_o}, and an assessment of directional stability for $C_{\Delta_o} = 2.75$, with the model constrained in roll.

Figures are included showing the limits and there are a number of subsidiary diagrams. Where possible results have been presented non-dimensionally.

Comparisons of the results obtained with those for other models (References 3 to 6) will be made in further reports; consideration is restricted in this report to factors peculiar to model D.

2. DESCRIPTION OF TESTS

2.1. General

All tests were made with one C.G. position, no slipstream, zero flap and at steady speeds only. The pitching moment of inertia of the model was 16.81 lb.ft.^{2} in all longitudinal stability tests.

2.2. Lift

A limited number of runs were performed at constant speed with the model clear of the water to check that there was no significant variation in lift from the values obtained for previous models, with which identical wings were used, these runs being carried out at several elevator settings and keel attitudes. The resulting curves are given in Figure 3.

2.3. Longitudinal Stability

Longitudinal stability tests were made by towing the model from the wing tips on the lateral axis through the centre of gravity, the model being free in pitch and heave. The value of the elevator setting was selected before each run, and the model towed at constant speed. The angle of trim was noted in the steady condition, and if the model proved stable at the speed selected it was given nose-down disturbances to determine whether instability could be induced, the amount of disturbance necessary to cause instability being in the range $0 - 9^{\circ}$. The larger amounts of disturbance were required near the undisturbed lower limit at high speeds. Stability limits were built up by these methods, the disturbed limits representing the worst possible case. Tests were carried out with $C_{\Delta_o} = 2.25$ and 2.75, and the corresponding trim curves and stability limits are given in Figures 4 - 7. The limits for the different values of C_{Δ_o} are plotted together in Figures 9 and 10 for comparison on a C_V base and the

/ undisturbed

undisturbed lower limits, transposed to a draught base by the formula of Reference 1 for the equivalent wedge, are plotted in Figure 11; Figures 12 and 13 are subsidiary curves necessary for this transposition.

When steady porpoising occurred, either with or without disturbance, the amplitude was noted, amplitude for this purpose being defined as the difference between the maximum and minimum trims attained in the oscillation. These amplitudes are plotted in Figures 14 and 15, for the various cases concerned.

In addition to the limits obtained with maximum disturbance, a graded set of limits with different fixed degrees of disturbance was obtained. These limits are given in Figure 8.

2.4. Spray and Wake Formation

Photographs were taken of the spray, from three different positions, over a range of speeds and with elevators set at -8^{o}. A number of these photographs are reproduced in Figures 18 to 21. They have been used to determine the projections of the spray envelopes on the plane of symmetry of the model at the different values of C_{Δ_o}, and these projections are plotted in Figure 22. This method of plotting differs from that originally proposed (Reference 1) but is felt to be more realistic. The absence of projections orthogonal to these, which cannot be obtained from the photographs, is not serious since the photographs enable the positions of the spray blisters to be judged qualitatively, and in any case the curves are intended for comparison purposes rather than for absolute measurements. It should be noted that in plotting the projections velocity spray has in general been ignored. The rather poor quality of the rear view spray photographs is due to the fact that they were taken with the aid of a mirror which was occasionally wetted by spray; such photographs as were of excessively poor quality have not been reproduced.

In addition to the spray photographs, photographs of the wake region were taken from two different positions and are reproduced in Figures 16 and 17. These photographs covered a range of speeds and elevator settings, the combinations being selected to give the maximum possible variation of wake formation and position relative to the afterbody in the stable planing region.

2.5. Directional Stability

In the directional stability tests the model was pivoted universally at the C.G. and then separately constrained in roll, so that it was effectively free in pitch, yaw and heave. The roll constraint was introduced after it had been ascertained on a previous model (Reference 3) that it had no appreciable effect on directional stability. The model was towed from the C.G. and moments to yaw the model were applied by means of strings attached to the wing tips and in the same horizontal plane as the C.G.

Steady speed runs were made with the elevators set at 0^{o}, the model being yawed up to at most 18 degrees and the values of yaw giving equilibrium determined by the operator by assessment of the direction of the resulting hydrodynamic moment on the model. The occurrence of very high drag forces at large angles of yaw at high speeds made it impossible to investigate some regions. The value of C_{Δ_o} in these tests was 2.75 and the resulting stability diagram is plotted in Figure 23; as it had previously been found (Reference 5) that load changes have little effect on directional stability it was not considered necessary to investigate directional characteristics at both values of C_{Δ_o}.

Similar tests with breaker strips fitted were not carried out on this model, as it has been found (Reference 1) that their effect is only to remove the outer lines of equilibrium at the higher speeds.

2.6. Elevator Effectiveness

Curves of elevator effectiveness calculated from the longitudinal stability diagrams are given in Figures 24 and 25.

3. DISCUSSION OF RESULTS

The lift curves (Figure 3) do not vary substantially from those for the basic model, with which identical wing and tail units were used.

The longitudinal stability of the model is poor. Only in the lower load case is there an uninterrupted stable band extending from zero to take-off speeds, and then only in the undisturbed case (Figure 4). There is an extremely marked deterioration in stability when disturbances are applied (cf. Figures 4 and 6 with Figures 5 and 7), and it can be seen from Figure 8, which shows limits obtained with different degrees of disturbance in the higher load case, that only relatively small disturbances are required to start instability in most parts of the diagram. (Figure 8 was prepared primarily for comparison with the corresponding diagram for the basic model of the series, and will be discussed in detail in a later report). The unstable areas at low attitudes and high speeds in the disturbed cases only appear when there is a large degree of disturbance; once instability has started in these regions, however, it is very violent. The amplitudes of porpoising at initially unstable points are considerably increased by disturbance, except at one or two isolated points where the amplitude is very large before disturbance. (Figures 14 and 15).

The effect of increased load on the stability is principally to produce an unstable band across the centre of the diagram in the undisturbed case, and to double the width of this band from load to load in the disturbed case, where it is present at both values of C_{Δ_0} used (Figures 9 and 10). There is also an increase in hump trim of about 1° and a corresponding increase in the values of the trim on the lower stability limits. There is no significant differenct between the trim curves as a whole in the two cases apart from a general slight increase in trim values for corresponding elevator settings, but the very high values of trim occurring at both values of C_{Δ_0} should be noted. Increase of load has little effect on the severity of porpoising (Figures 14 and 15), probably because the porpoising is already so severe at the lower load.

The two undisturbed lower limits have been transferred to a draught base (Figure 11) by the formula derived in Reference 1. The load effect on the draught at these limits is small.

The load coefficient curves of Figures 12 and 13, which are necessary in calculating the limits on a draught base, can also be used to estimate flying speeds, but it should be noted that no allowance for ground effect has been made in them.

Photographs of the flow in the wake (Figures 16 and 17) are included to show the position of the afterbody relative to the wake in representative positions so that, amongst other things, its association with instability can be investigated. Figure 16(a) shows a typical configuration at near-hump speed and attitude. The afterbody can be seen to be touching the wake near the rear step; at this setting, the model becomes unstable for small disturbances, with two-step porpoising resulting. 16(b) and (c) are both in the mid-planing region, and in both cases the afterbody is touching the wake; case (b) is unstable when disturbed but case (c) is not. The speed for case (c) is a little higher than for case (b), and possibly is too high for two-step porpoising to occur so that when the afterbody touches the wake there is damping rather than an accentuation of porpoising. The remaining photographs of the set, 16(d) and (e), show the model at two settings just within the

/ undisturbed

undisturbed lower limit. The afterbody is well clear of the wake in both cases, so that there is full opportunity for forebody porpoising, which in fact occurs for small disturbances.

Very similar remarks apply to Figure 17. Here (a) is the near-hump case, (c) and (d) the mid-planing and (e) the lower limit cases. (b) shows the wake at a high speed stable position. The relative afterbody positions are similar to those for Figure 16 except that there is no wake interference in the two mid-planing cases; both these cases are unstable with disturbance. It should be noted that the points chosen do not correspond directly with those for Figure 16.

Figures 18 - 21 show the spray formation at one elevator setting, a range of speeds and two loads. This is not of such a nature as to create any difficulty, since only velocity spray enters regions where propellers or jet intakes would be situated. There is some deterioration of spray behaviour with increase in load; Figure 22 shows the projection of the spray envelopes on the plane of symmetry of the model at the two loads, where this effect is easier to see, but the change is not large enough to be significant.

Details of the interpretation of the directional stability diagram (Figure 23) have already been given in Reference 1. In view of the changes in the nature of some parts of the diagram from the case considered there, however, some further comment is necessary. Between C_V = 3 and 5 the model is in stable equilibrium at zero yaw but when it is yawed out to a certain angle (depending on the speed) the lower section only of the flow in the wake attaches to the afterbody near the rear step and gives rise to a very small suction which tends to yaw the model further. This is the reason for the existence of the line of unstable equilibrium. It is only necessary, however, for the model to be yawed out a very small amount beyond this line before the resulting pressures on the hull balance the suction on the afterbody, and the model is in stable equilibrium again. Hence there is a line of stable equilibrium very close to that of unstable equilibrium; it is in fact so close between C_V = 4.0 and 4.7 as to make it impossible to determine the positions of the lines experimentally. When C_V is greater than about 4.4, if the model is yawed beyond the outer line of stable equilibrium the upper section of the flow in the wake also attaches to the afterbody so that there is a further short line of unstable equilibrium. Between C_V = 5 and 7 longitudinal instability occurs when the model is yawed and directional characteristics cannot be ascertained.

Finally, a word may be said on the effect of load on elevator effectiveness (Figures 24 and 25). The decrease in effectiveness is more noticeable in the diagrams of $d\alpha_K/d\eta$ against η at constant C_V than those of mean $d\alpha_K/d\eta$ against C_V, but is not large in either case.

4. CONCLUSIONS

The tests performed indicate that this model has poor hydrodynamic properties in calm water, except at low loadings, and extremely bad ones in rough water at any loading. Spray characteristics are good, but mainly result from extremely high attitudes which would not be permissible full-scale.

/ LIST OF SYMBOLS

LIST OF SYMBOLS

b	beam of model
d	draught
C_L	lift coefficient $= L/\frac{1}{2}\rho\, SV^2$ (L = lift, ρ = air density).
C_V	velocity coefficient $= V/\sqrt{gb}$
C_Δ	load coefficient $= \Delta/wb^3$ (Δ = load on water and w = weight per unit volume of water)
C_{Δ_o}	load coefficient at $V = 0$
C_X	longitudinal spray coefficient $= x/b$
C_Y	lateral spray coefficient $= y/b$
C_Z	vertical spray coefficient $= z/b$
	$\{(x,y,z)$ co-ordinates of points on spray envelope relative to axes through step point$\}$
S	gross wing area
V	velocity
α_K	keel attitude
η	elevator setting
ψ	angle of yaw

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/ LIST OF REFERENCES

LIST OF REFERENCES

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5	J. K. Friswell D. M. Ridland A. G. Kurn	Investigation of High Length/Beam Ratio Seaplane Hulls with High Beam Loadings: Hydrodynamic Stability Part 5: The Stability and Spray Characteristics of Model C. M.A.E.E. Report F/Res/239. October 1953.
6	D. M. Ridland	Investigation of High Length/Beam Ratio Seaplane Hulls with High Beam Loadings: Hydrodynamic Stability Part 6: The Effect of Forebody Warp on Stability and Spray Characteristics. M.A.E.E. Report F/Res/240. (To be issued shortly).

/ TABLE I

TABLE I

Models for hydrodynamic stability tests

Model	Forebody warp	Afterbody length	Afterbody-forebody keel angle	Step form	To determine effect of
	degrees per beam	beams	degrees		
A	0	5	6	Unfaired transverse. Step depth 0.15 beam.	Forebody warp
B	4	5	6		
C	8	5	6		
D	0	4	6		Afterbody length
A	0	5	6		
E	0	7	6		
F	0	9	6		
G	0	5	4		Afterbody angle
A	0	5	6		
H	0	5	8		

/ TABLE II

TABLE II

MODEL D - HYDRODYNAMIC DATA

Beam at step (b)	0.475'
Length of forebody (6b)	2.850'
Length of afterbody (4b)	1.900'
Angle between forebody and afterbody keels	6°
Forebody deadrise at step	25°
Forebody warp (per beam)	Nil
Afterbody deadrise	30°
	(decreasing to 26° at main step over forward 40% of afterbody length).
Pitching moment of inertia	16.81 lb.ft.^{2}

/ TABLE III

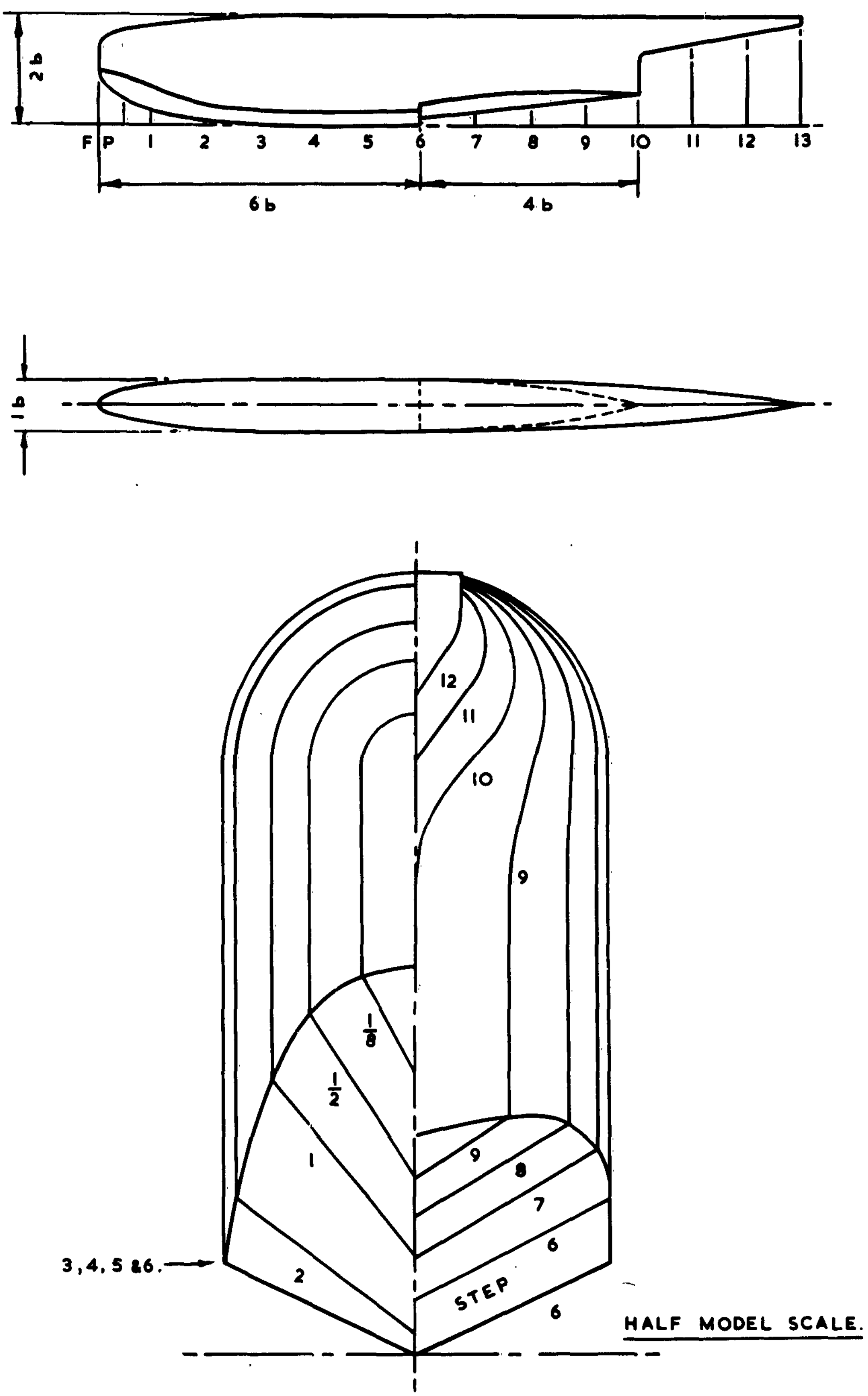
TABLE III

Model Aerodynamic data

Mainplane	
Section	Gottingen 436 (mod.)
Gross area	6.85 sq. ft.
Span	6.27 ft.
S.M.C.	1.09 ft.
Aspect ratio	5.75
Dihedral (on 30% spar axis)	3° 0'
Sweepback (on 30% spar axis)	4° 0'
Wing setting (root chord to hull datum)	6° 9'
Tailplane	
Section	R.A.F. 30 (mod.)
Gross area	1.33 sq. ft.
Span	2.16 ft.
Total elevator area	0.72 sq. ft.
Tailplane setting (root chord to hull datum)	2° 0'
Fin	
Section	R.A.F. 30
Gross area	0.80 sq. ft.
Height	1.14 ft.
General	
* C.G. position	
distance forward of step point	0.237 ft.
distance above step point	0.731 ft.
* $\frac{1}{4}$ chord point S.M.C.	
distance forward of step point	0.277 ft.
distance above step point	1.015 ft.
* Tail arm (C.G. to hinge axis)	3.1 ft.
* Height of tailplane root chord L.E. above hull crown	0.72 ft

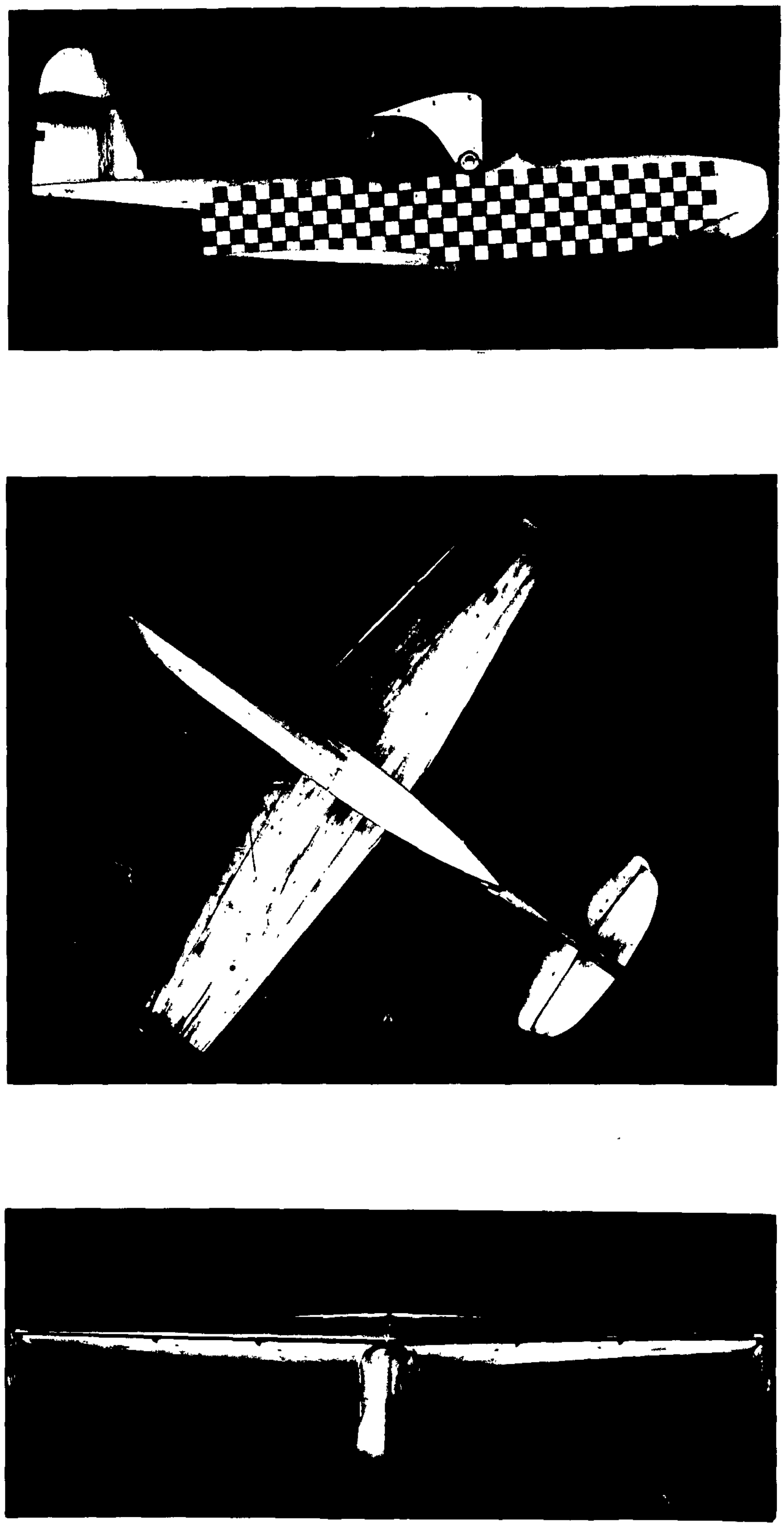
* These distances are measured either parallel to or normal to the hull datum.

FIG.1.



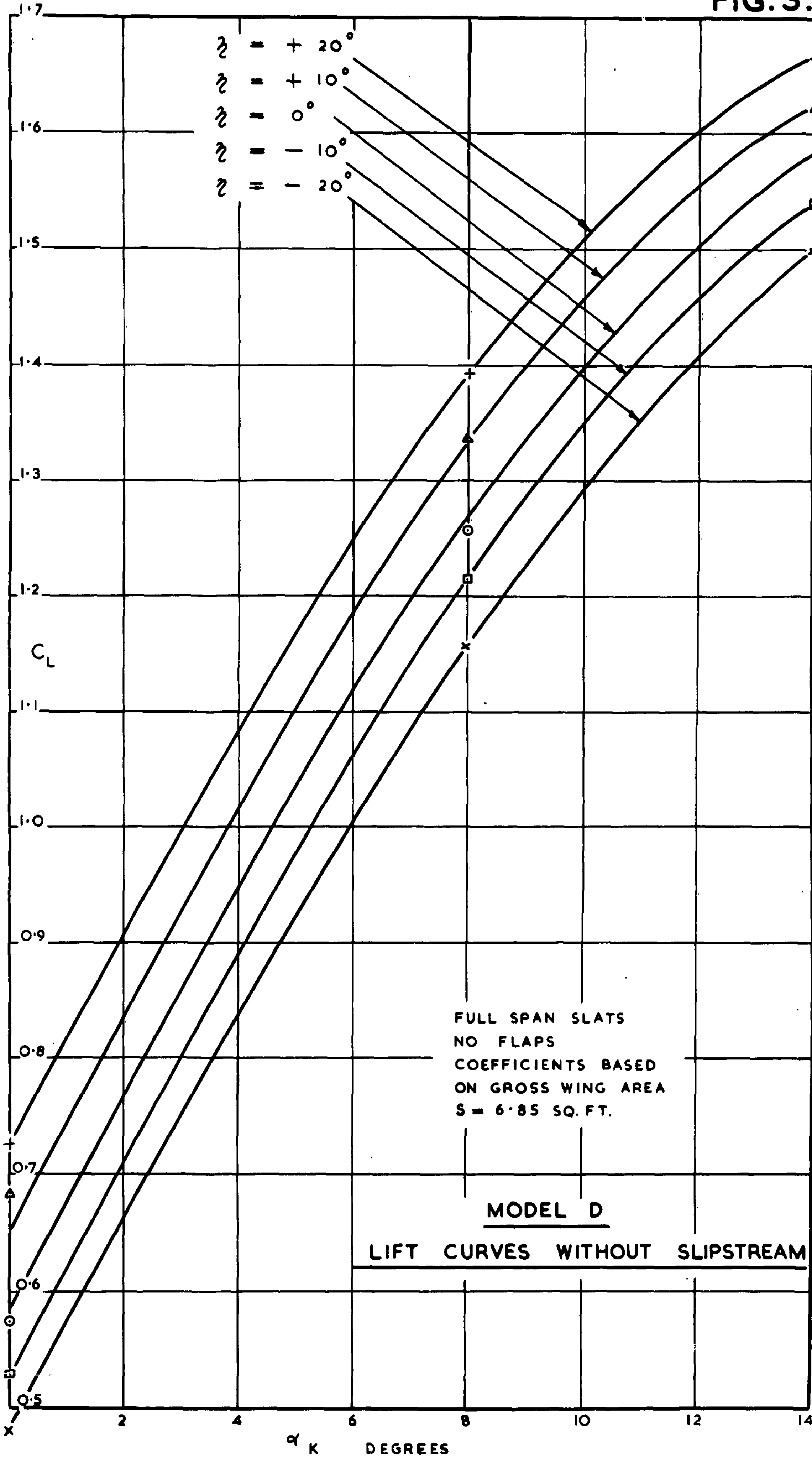
MODEL D
HULL LINES

FIG. 2



.PHOTOGRAPHS OF MODEL D

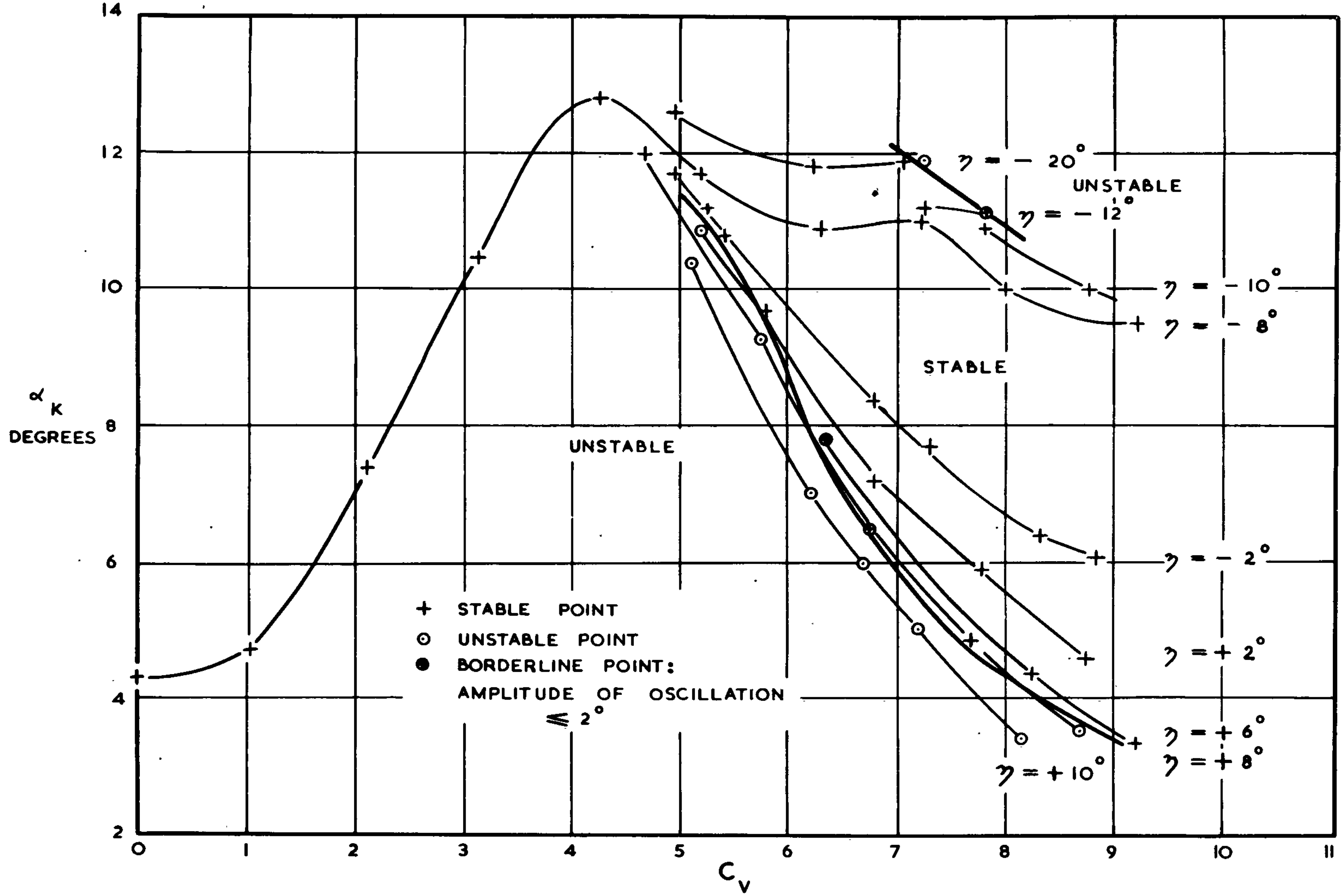
FIG. 3.



MODEL D

LIFT CURVES WITHOUT SLIPSTREAM

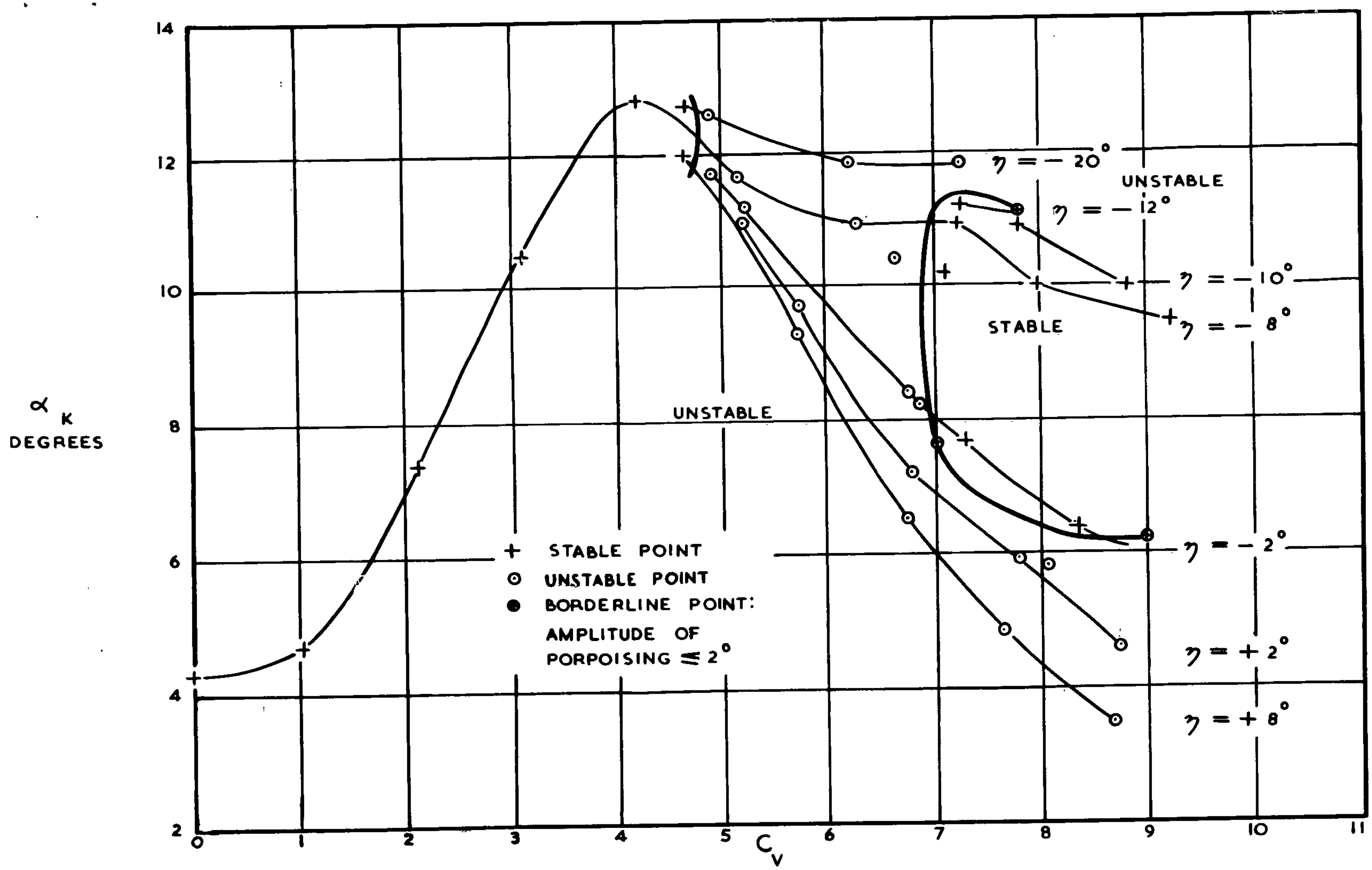
FIG. 4.



MODEL D

LONGITUDINAL STABILITY WITHOUT DISTURBANCE, $C_{\Delta_o} = 2{\cdot}25$.

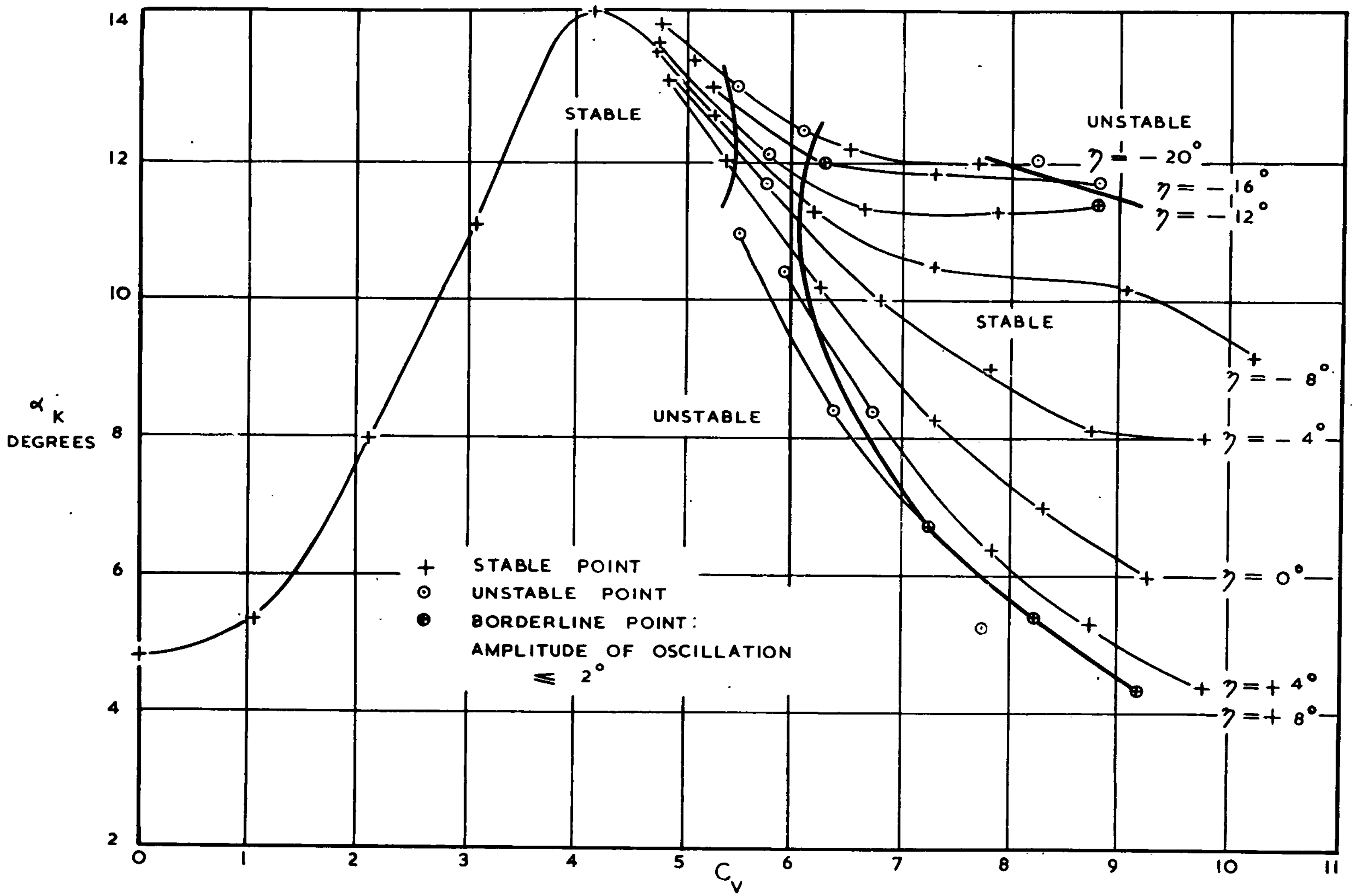
FIG.5.



MODEL D

LONGITUDINAL STABILITY WITH DISTURBANCE, $C_{\Delta_0} = 2{\cdot}25$.

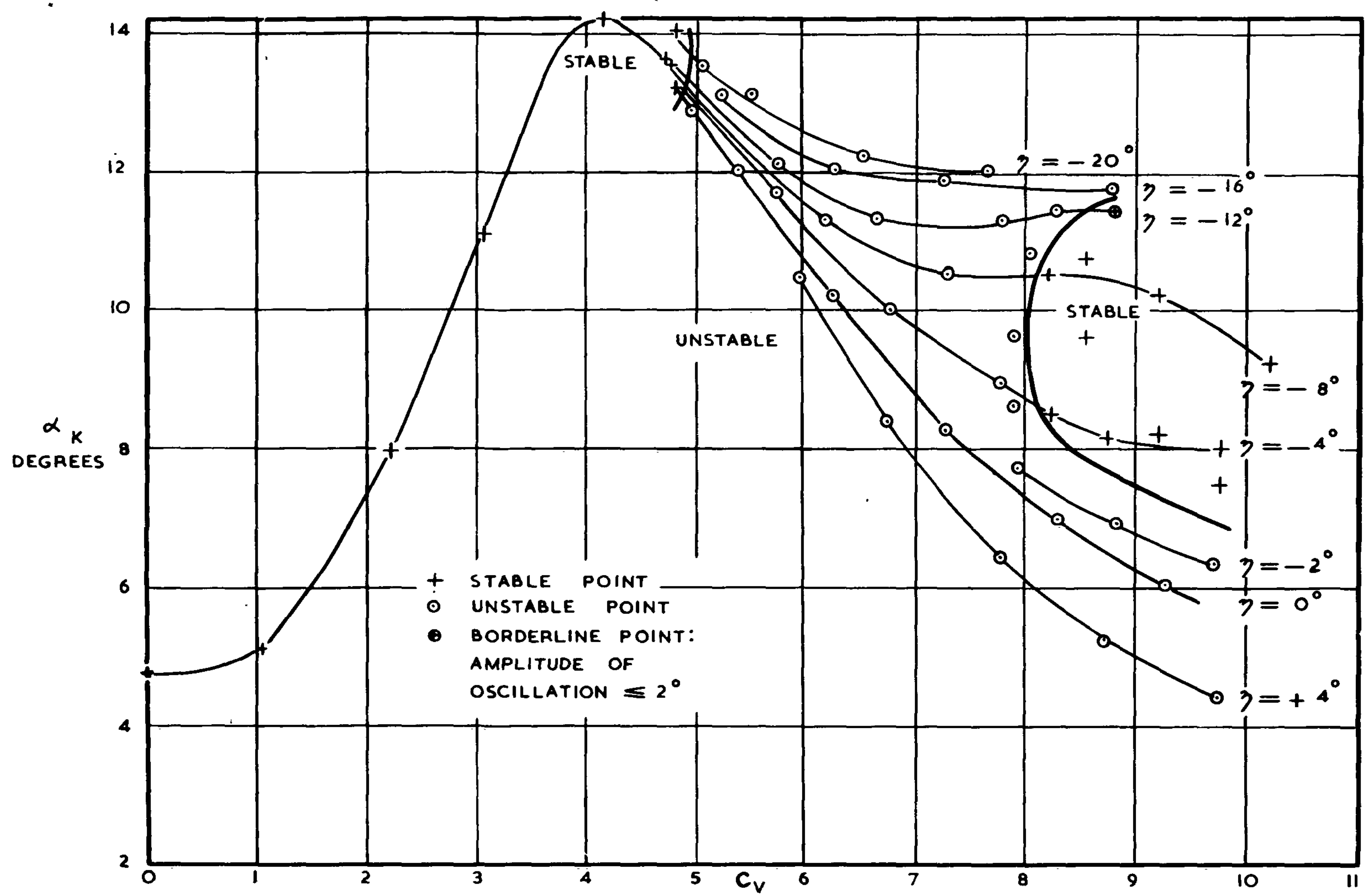
FIG. 6.



MODEL D

LONGITUDINAL STABILITY WITHOUT DISTURBANCE, $C_{\Delta_0} = 2{\cdot}75$.

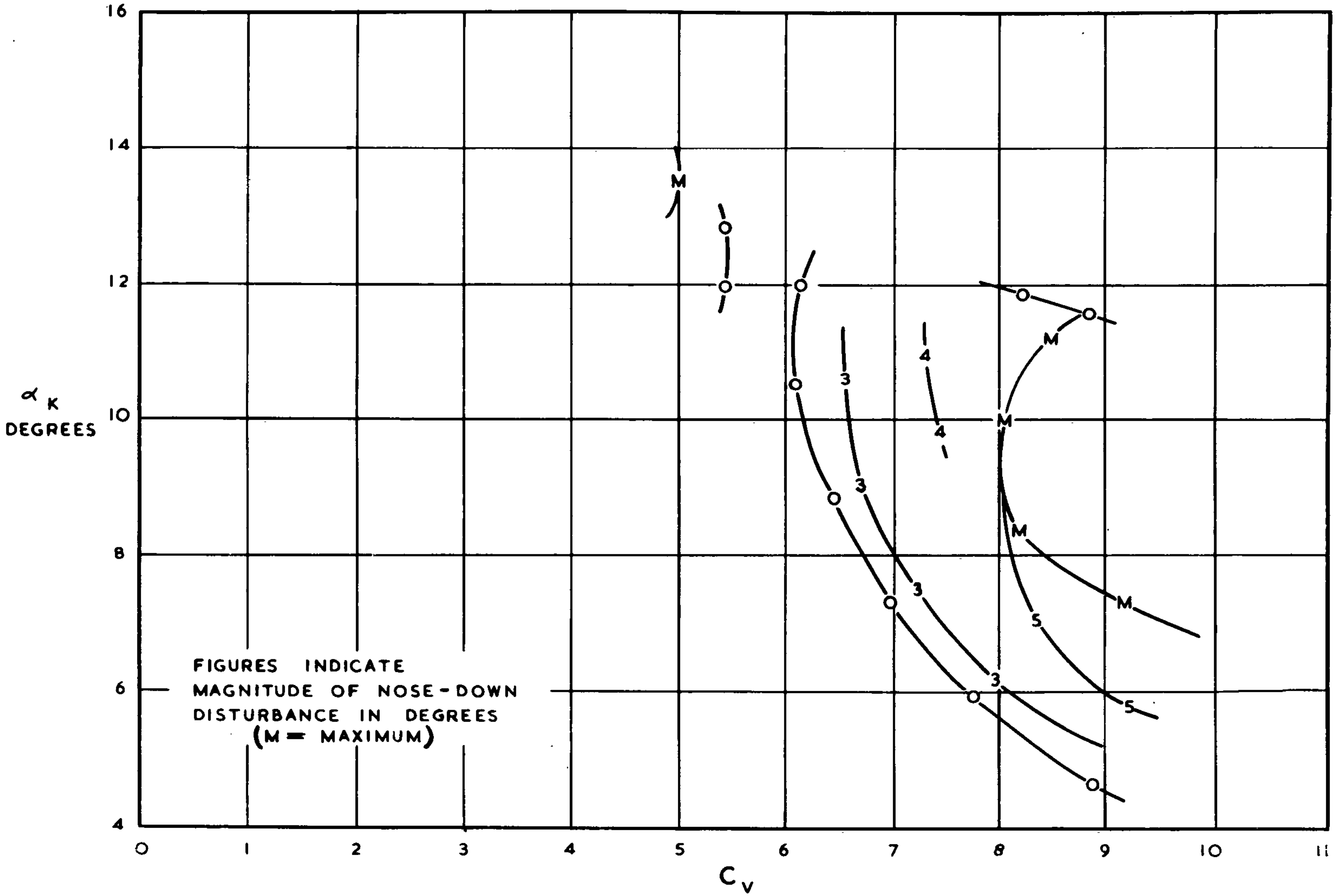
FIG. 7.



MODEL D

LONGITUDINAL STABILITY WITH DISTURBANCE, $C_{\Delta_0} = 2\cdot75$.

FIG. 8.



MODEL D

STABILITY LIMITS FOR DIFFERENT MAGNITUDES OF DISTURBANCE, $C_{\Delta_0} = 2 \cdot 75$.

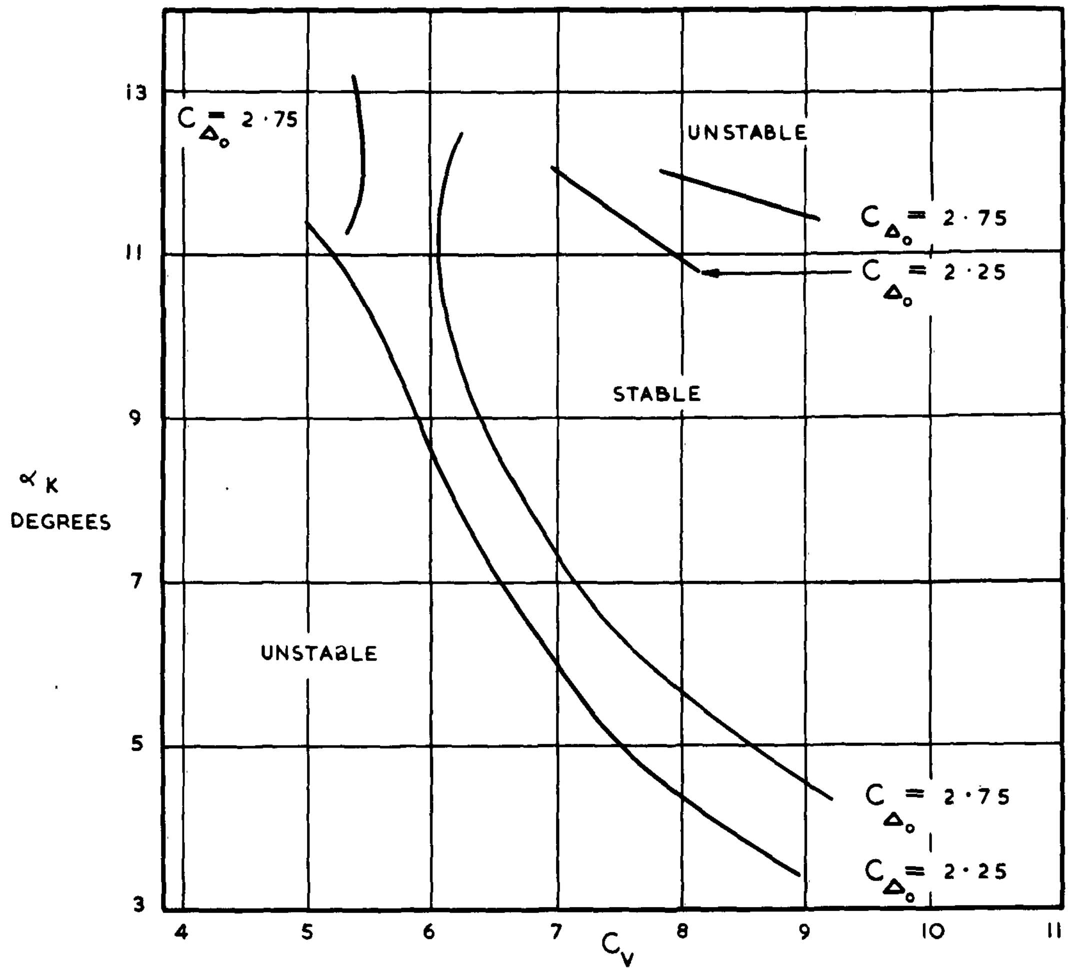


FIG.9. COMPARISON OF UNDISTURBED LONGITUDINAL STABILITY LIMITS ON A C_V BASE, MODEL D.

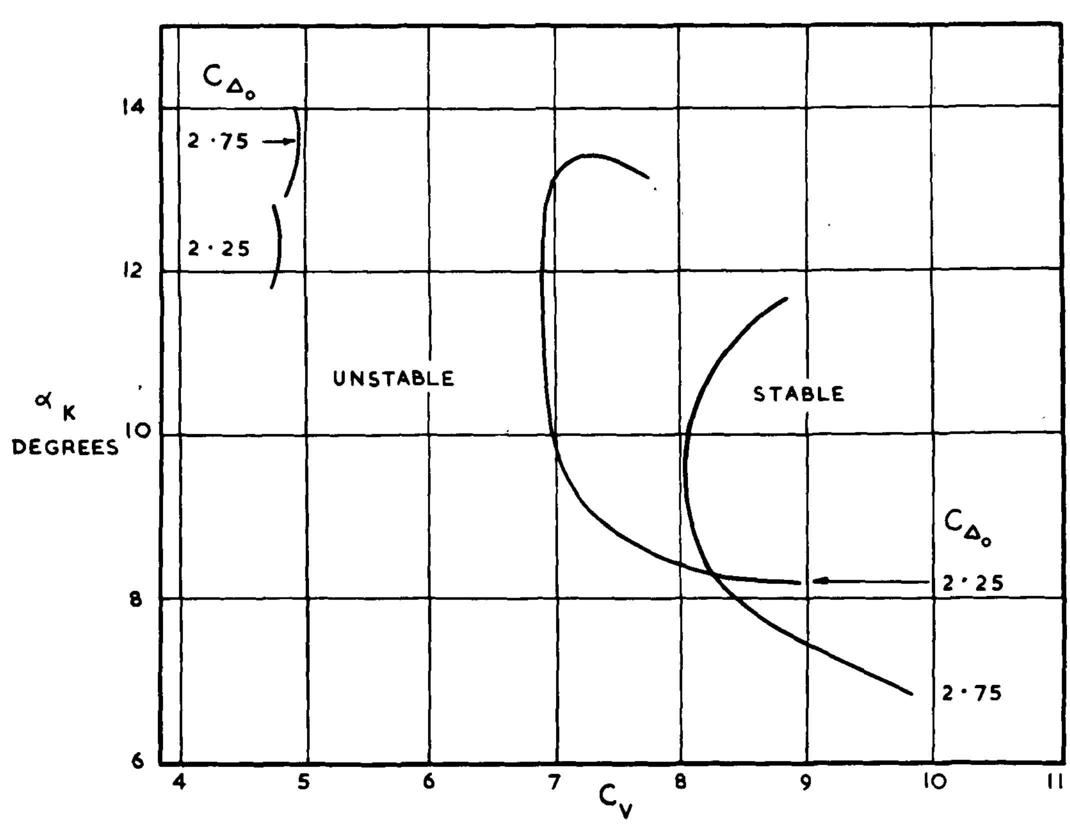
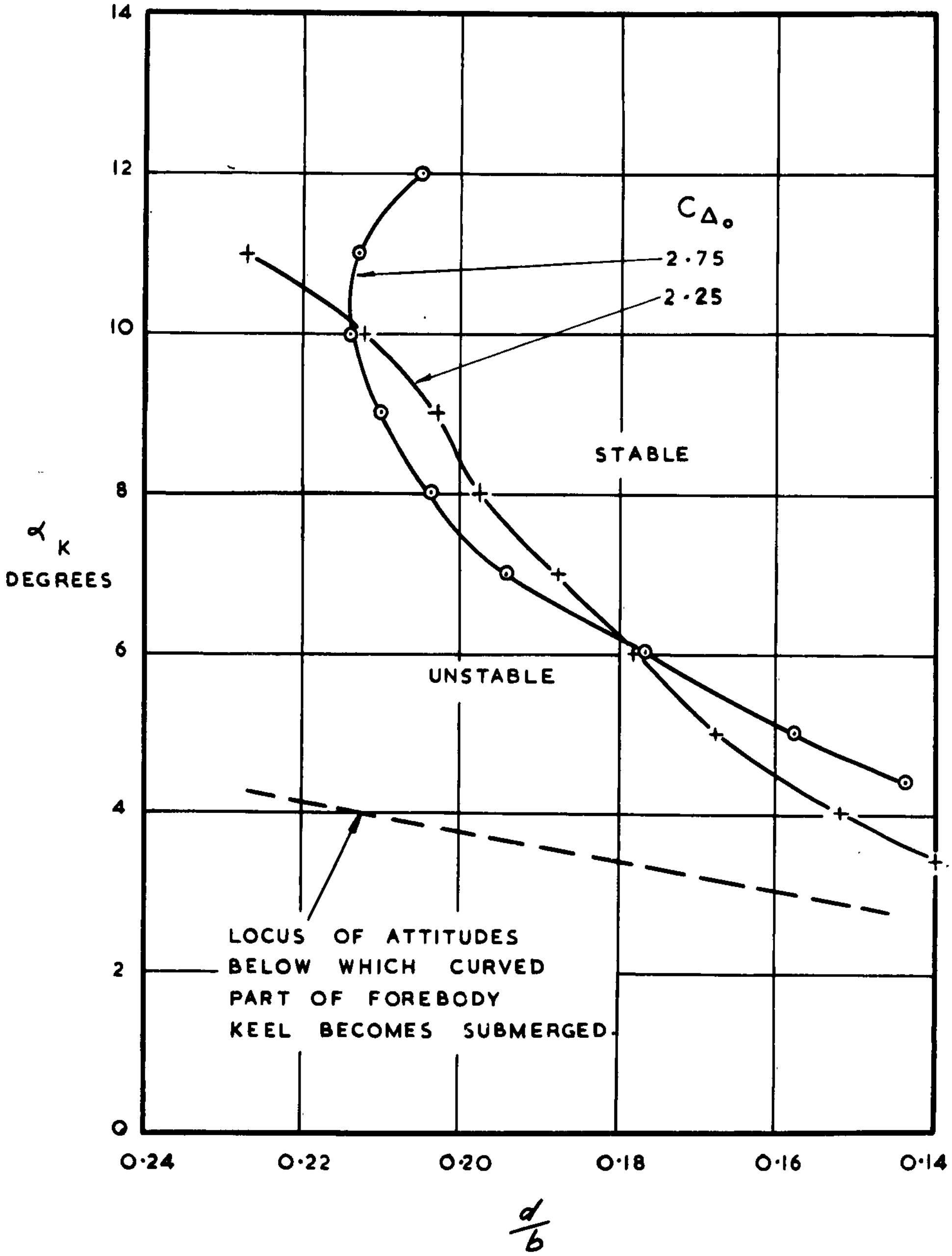


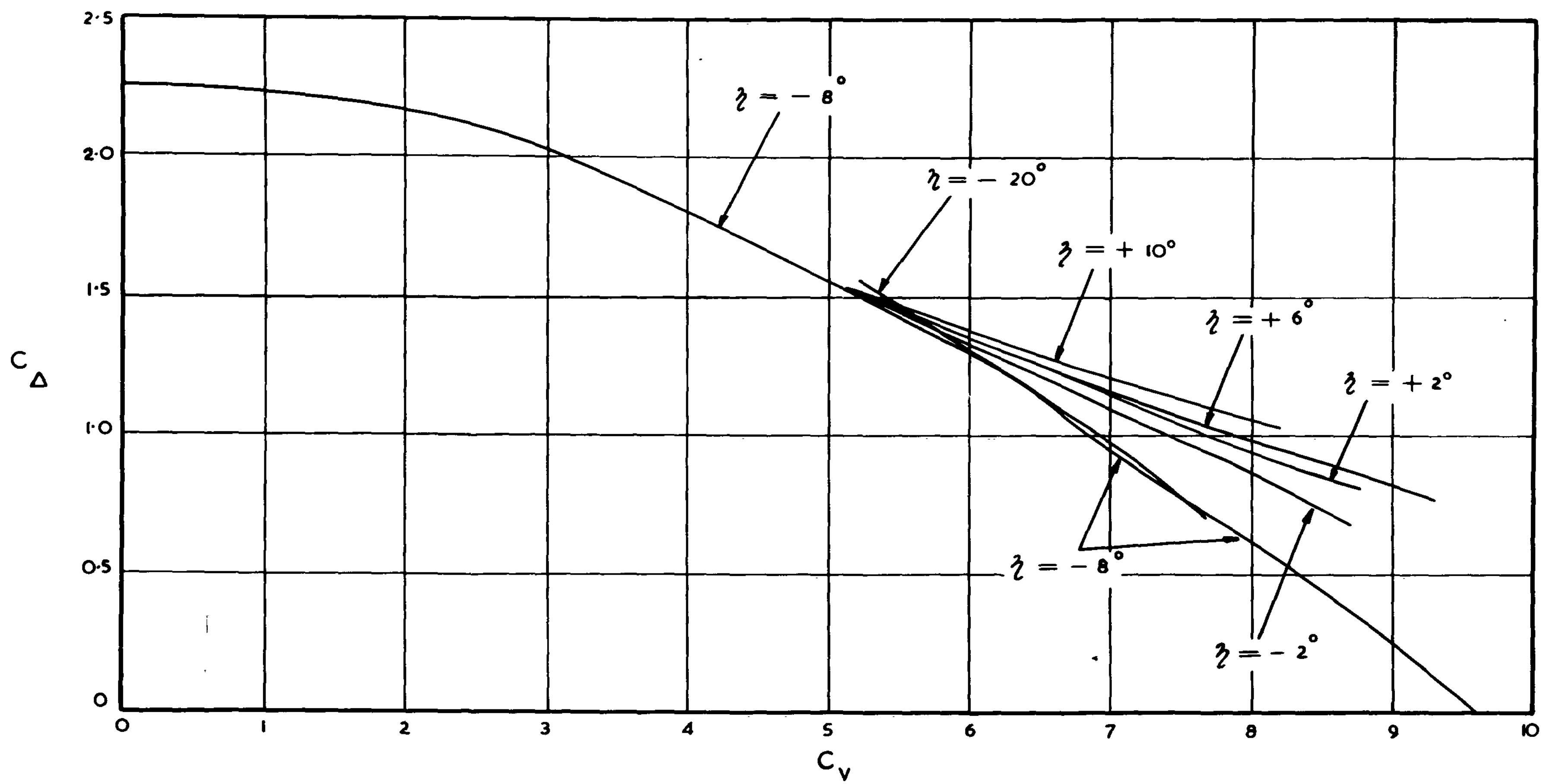
FIG.10. COMPARISON OF DISTURBED LONGITUDINAL STABILITY LIMITS ON A C_V BASE, MODEL D.



MODEL D

COMPARISON OF LOWER UNDISTURBED LONGITUDINAL STABILITY LIMITS ON A DRAUGHT BASE

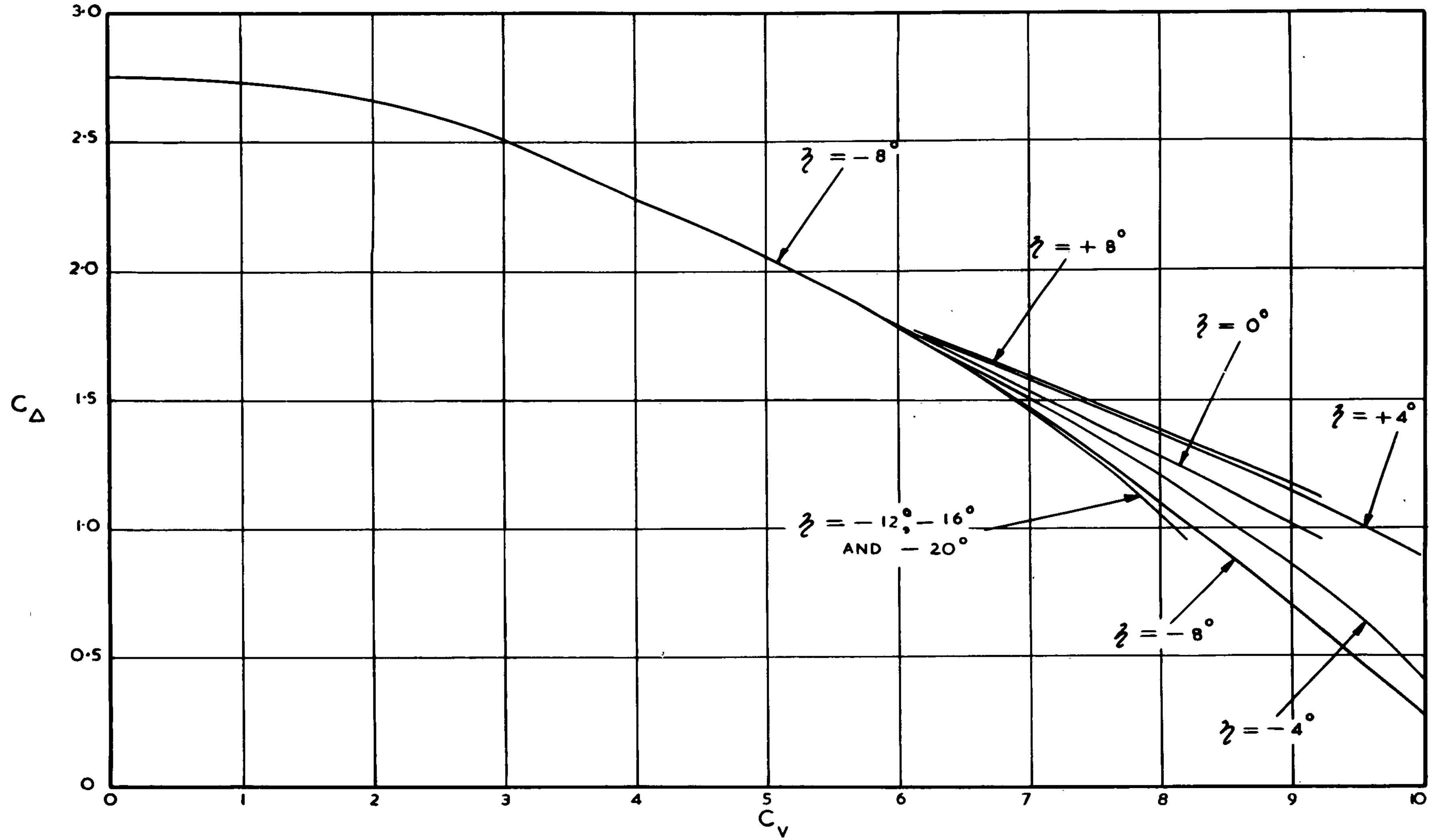
FIG. 12.



MODEL D

LOAD COEFFICIENT CURVES, $C_{\Delta_0} = 2{\cdot}25$.

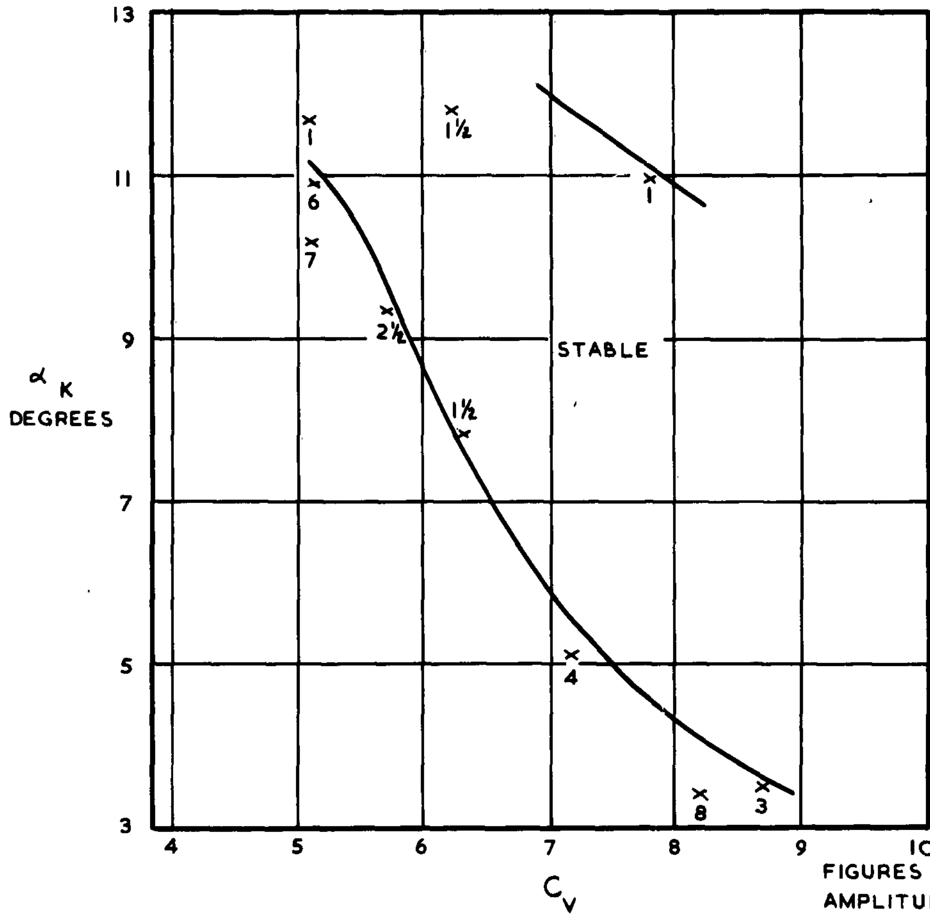
FIG.13.



MODEL D

LOAD COEFFICIENT CURVES, $C_{\Delta_0} = 2·75$.

FIG.14.



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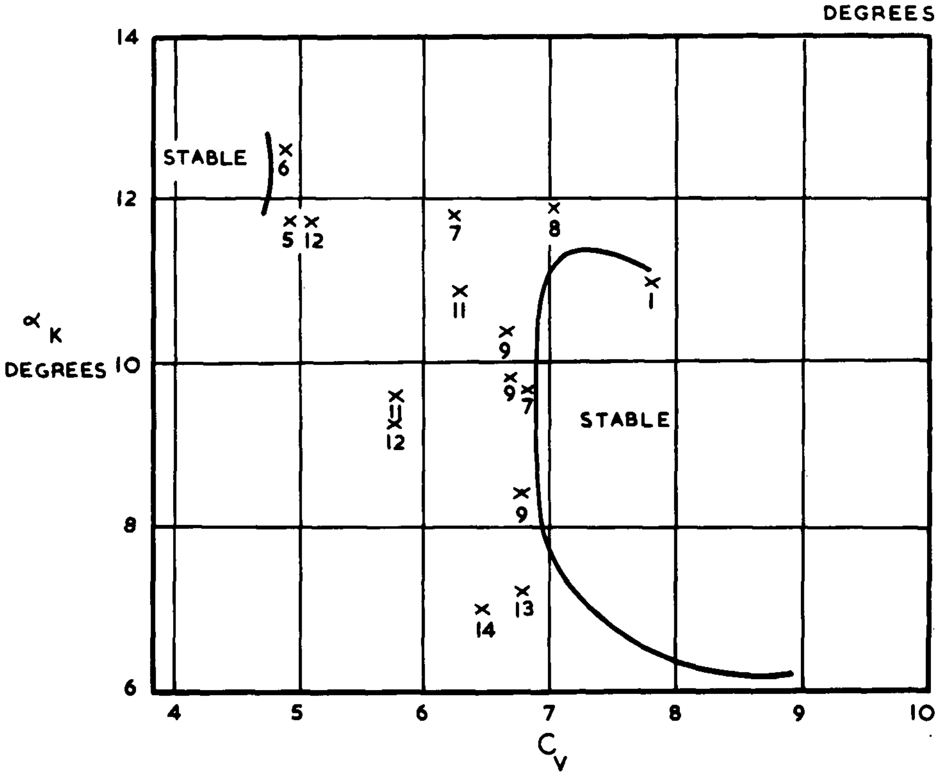
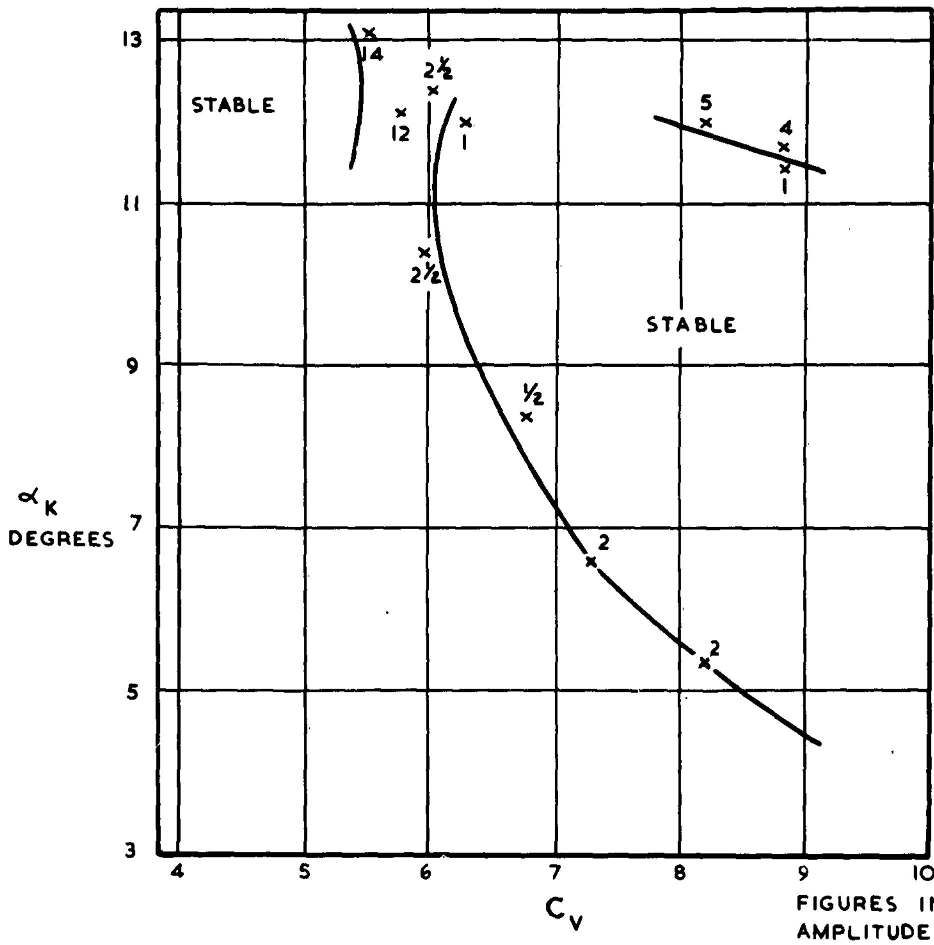
FIGURES INDICATE AMPLITUDES OF PORPOISING IN DEGREES



DISTURBED CASE

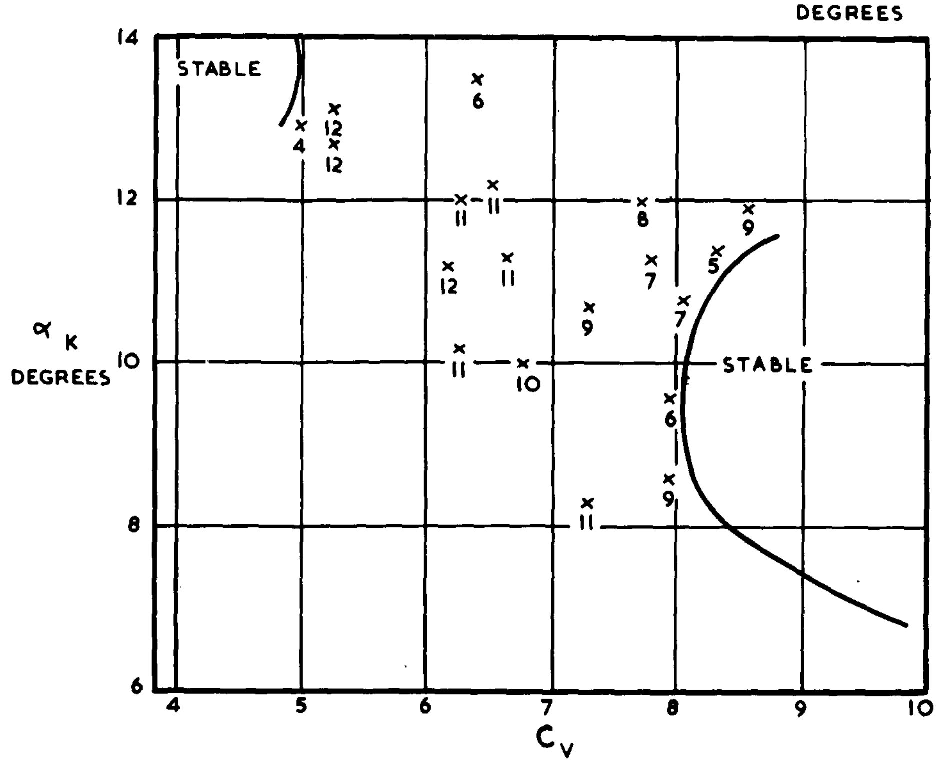
MODEL D
PORPOISING AMPLITUDES AND STABILITY LIMITS
$C_{\Delta_0} = 2 \cdot 25$

FIG. 15.



UNDISTURBED CASE

FIGURES INDICATE AMPLITUDES OF PORPOISING IN DEGREES



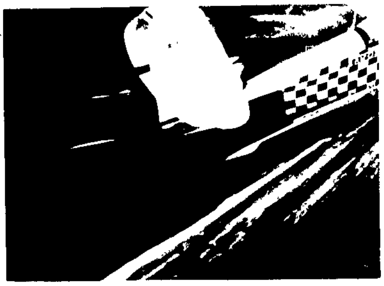
DISTURBED CASE

MODEL D

PORPOISING AMPLITUDES AND STABILITY LIMITS

$C_{\Delta_0} = 2 \cdot 75$

FIG. 16

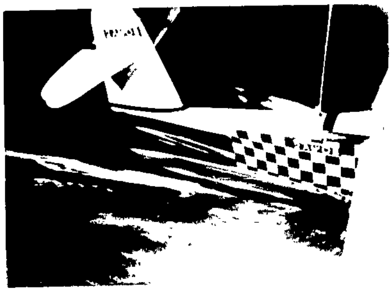


(a)

$\eta = -8^\circ$

$C_V = 4{\cdot}98$

$\alpha_K = 11{\cdot}9^\circ$

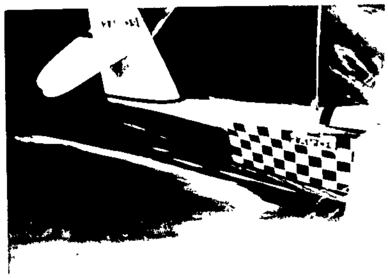


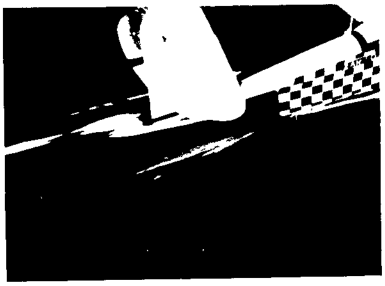
(b)

$\eta = -12^\circ$

$C_V = 6{\cdot}26$

$\alpha_K = 11{\cdot}2^\circ$



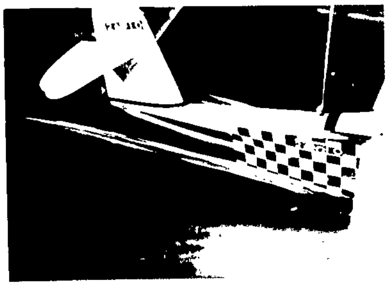


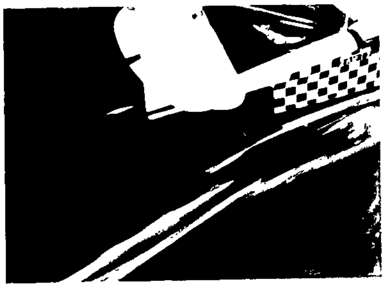
(c)

$\eta = -10^\circ$

$C_V = 7{\cdot}98$

$\alpha_K = 10{\cdot}7^\circ$



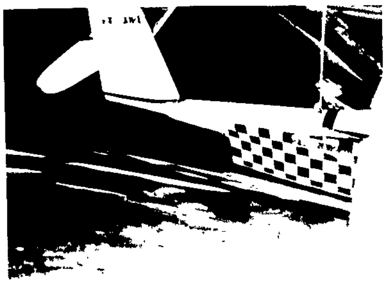


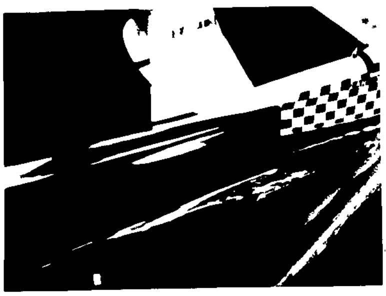
(d)

$\eta = +2^\circ$

$C_V = 6{\cdot}27$

$\alpha_K = 7{\cdot}8^\circ$



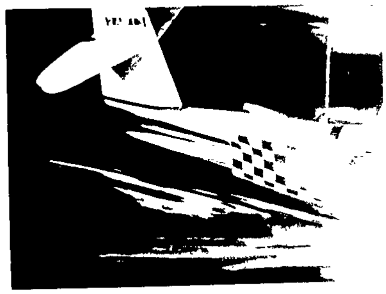


(e)

$\eta = +2^\circ$

$C_V = 8{\cdot}96$

$\alpha_K = 4{\cdot}2^\circ$

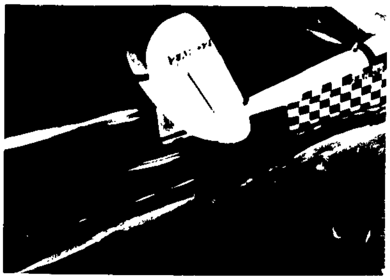


MODEL D

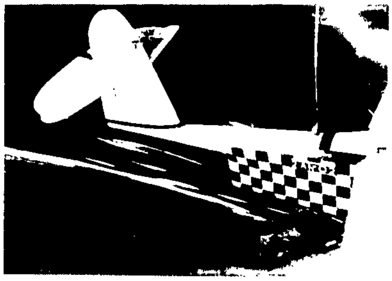
WAKE PHOTOGRAPHS

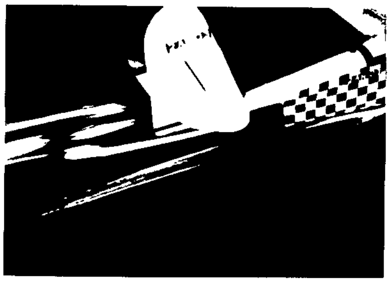
$C_{\Delta_0} = 2{\cdot}25$

FIG. 17

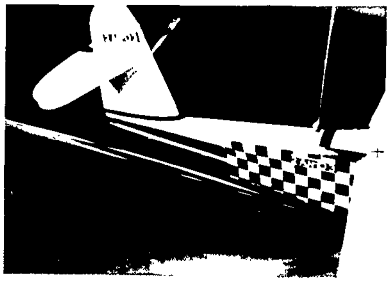


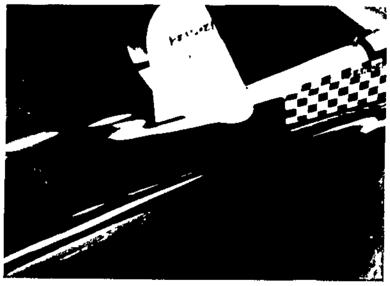
(a)
$\eta = -20°$
$C_V = 6{\cdot}72$
$\alpha_K = 12{\cdot}1°$



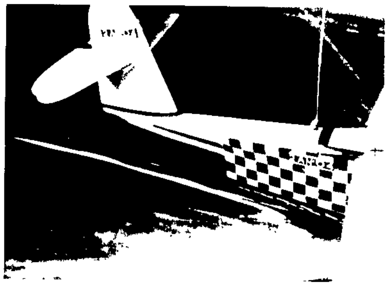


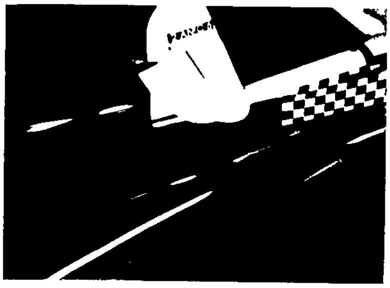
(b)
$\eta = -10°$
$C_V = 8{\cdot}96$
$\alpha_K = 10{\cdot}8°$



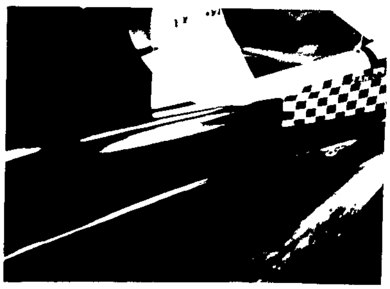


(c)
$\eta = -6°$
$C_V = 7{\cdot}8$
$\alpha_K = 9{\cdot}8°$

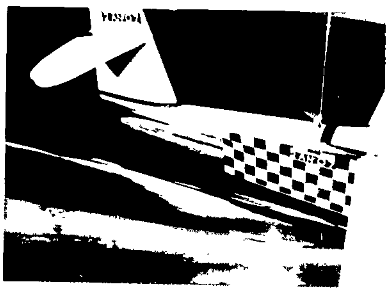




(d)
$\eta = +2°$
$C_V = 6{\cdot}52$
$\alpha_K = 9{\cdot}4°$



(e)
$\eta = +2°$
$C_V = 9{\cdot}11$
$\alpha_K = 5{\cdot}6°$



MODEL D

WAKE PHOTOGRAPHS

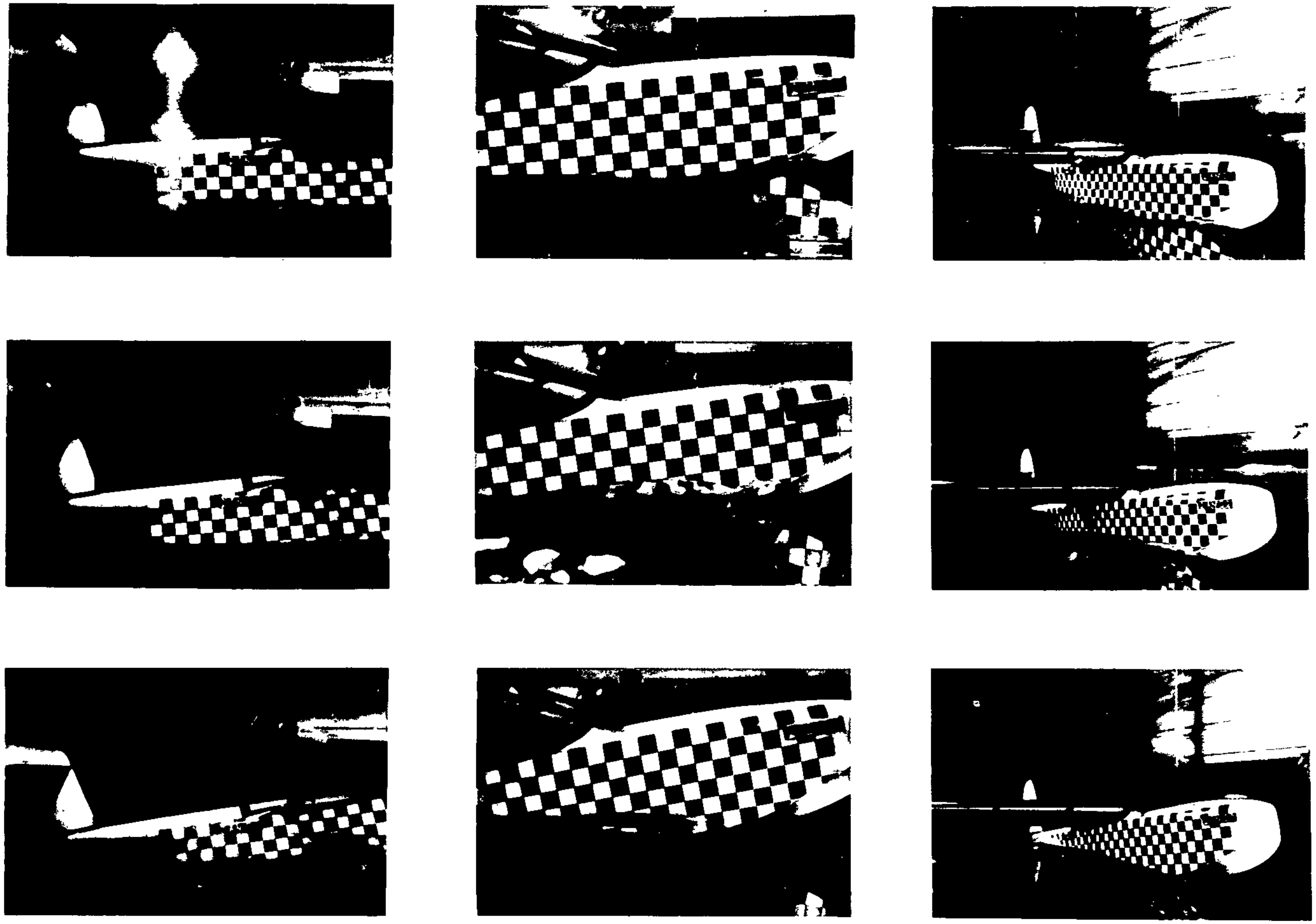
$C_{\Delta_0} = 2{\cdot}75$

FIG. 18

(a)
$\eta = -8°$
$C_v = 1{\cdot}02$
$\alpha_K = 4{\cdot}7°$

(b)
$\eta = -8°$
$C_v = 1{\cdot}99$
$\alpha_K = 7{\cdot}1°$

(c)
$\eta = -8°$
$C_v = 3{\cdot}07$
$\alpha_K = 10{\cdot}2°$



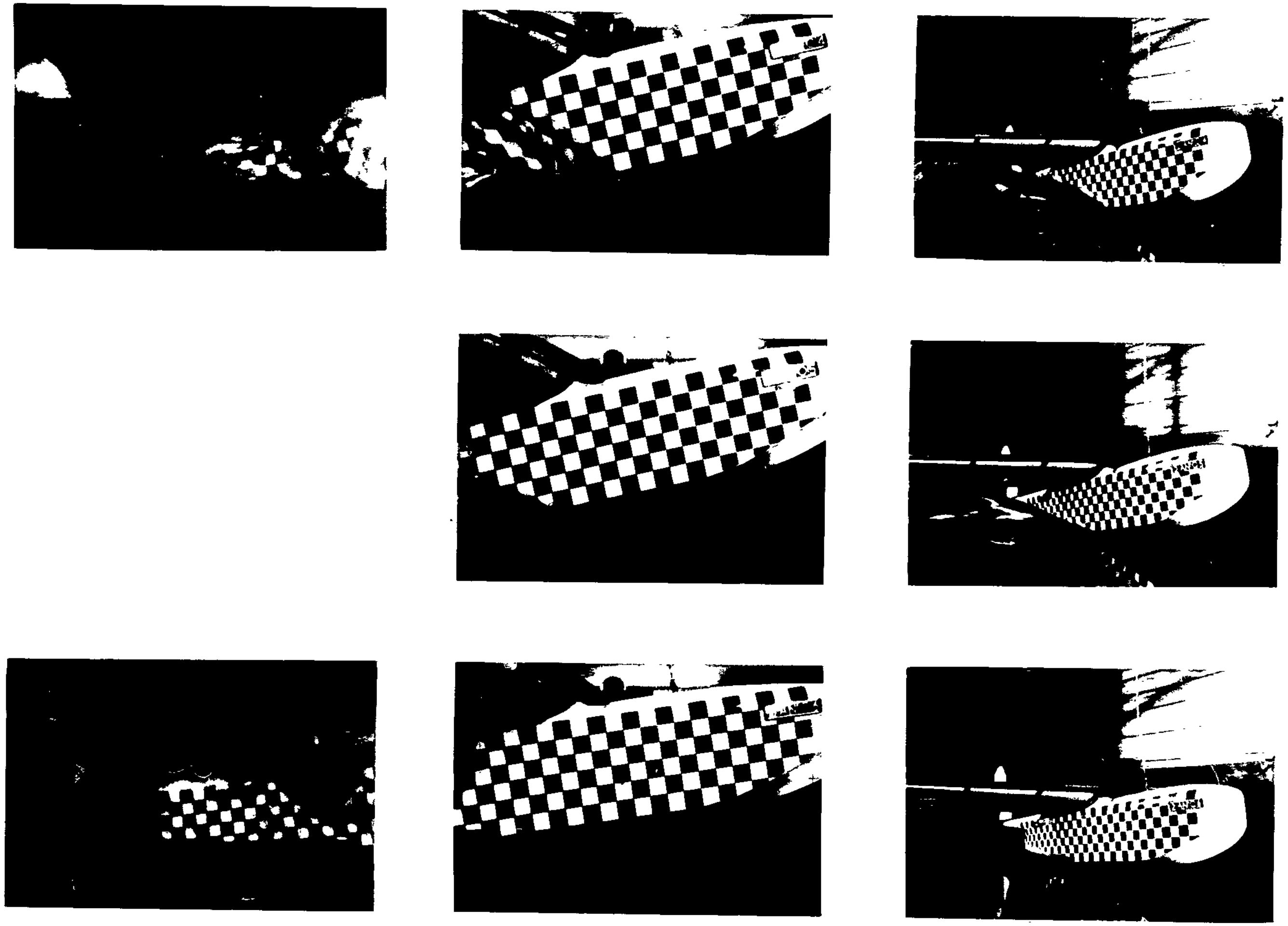
MODEL D

SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 2\ 25$, (1)

(a)
$\eta = -8^\circ$
$C_v = 4.15$
$\alpha_K = 12.8^\circ$

(b)
$\eta = -8^\circ$
$C_v = 4.98$
$\alpha_K = 11.9^\circ$

(c)
$\eta = -8^\circ$
$C_v = 8.96$
$\alpha_K = 9.6^\circ$



MODEL D

SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 2.25$,(2)

FIG. 19

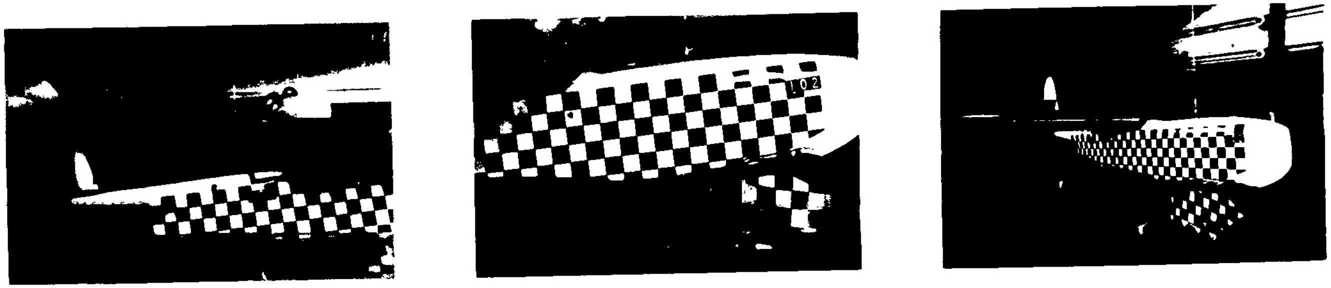
FIG 20

(a)

$\zeta = -8^\circ$

$C_v = 1 \cdot 02$

$\alpha_k = 5 \cdot 1^\circ$

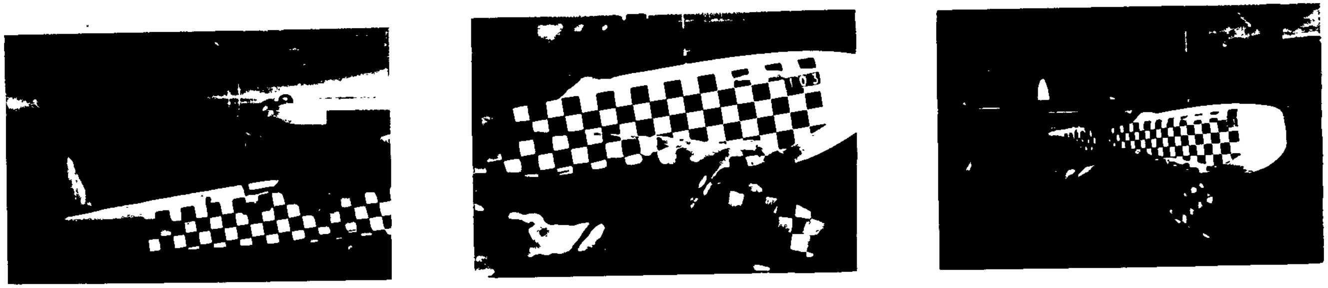


(b)

$\zeta = -8^\circ$

$C_v = 2 \cdot 05$

$\alpha_k = 7 \cdot 8^\circ$

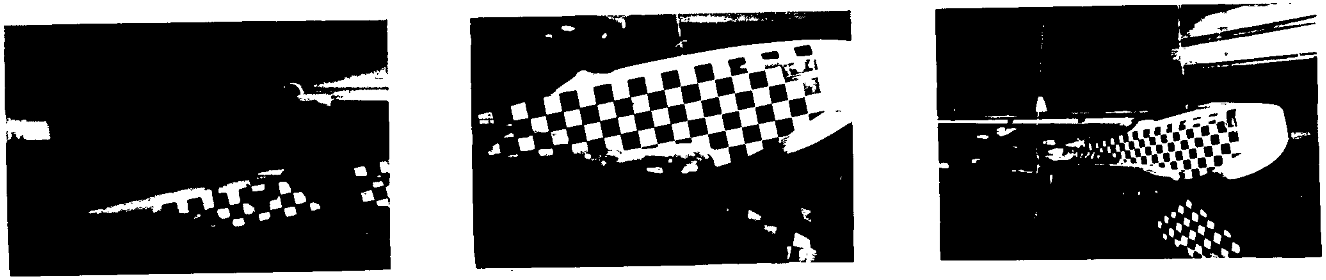


(c)

$\zeta = -8^\circ$

$C_v = 3 \cdot 07$

$\alpha_k = 11 \cdot 1^\circ$



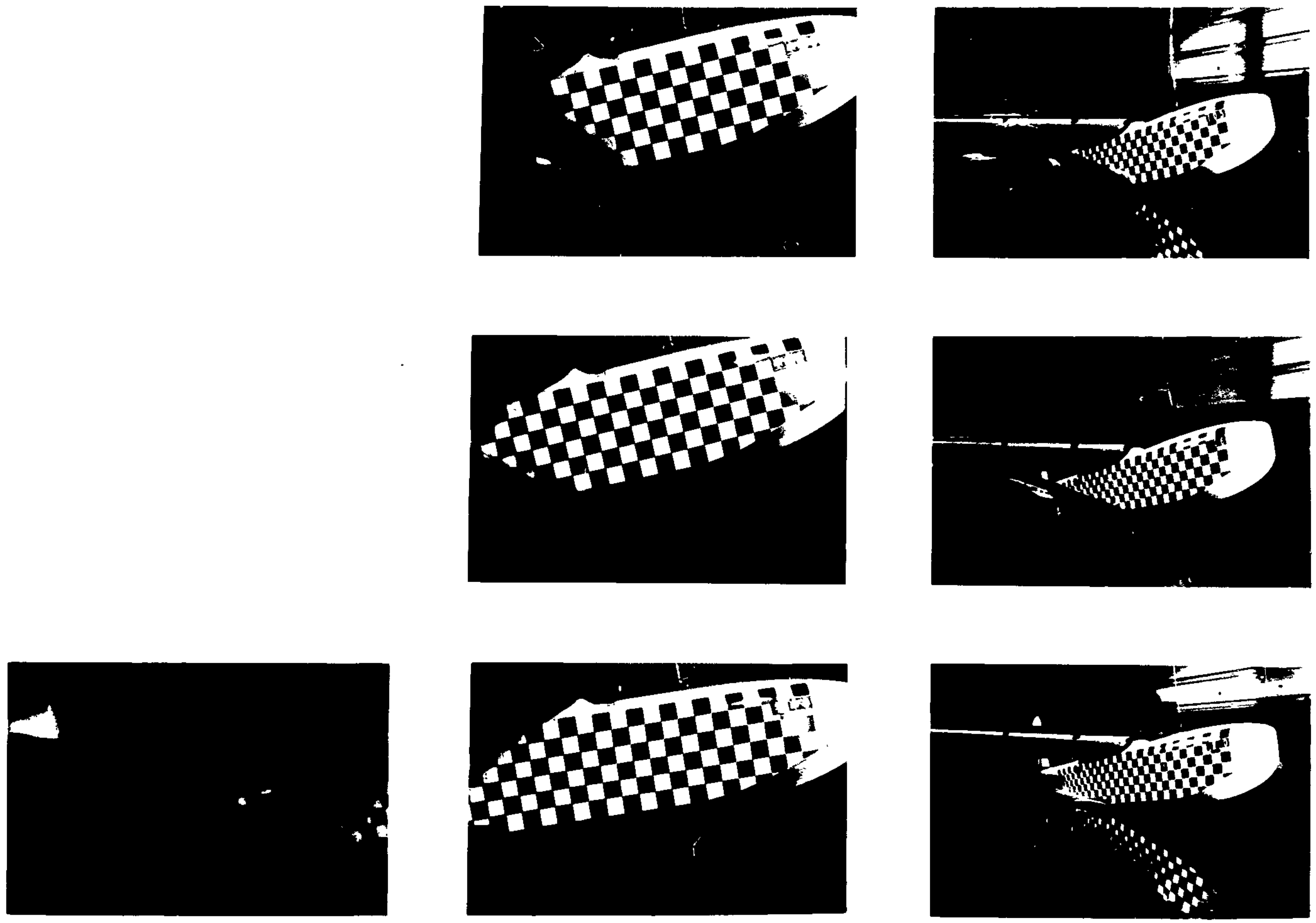
MODEL D

SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 2 \cdot 75$,(I)

(a)
$\eta = -8^\circ$
$C_v = 4.09$
$\alpha_k = 14.2^\circ$

(b)
$\eta = -8^\circ$
$C_v = 5.12$
$\alpha_k = 12.9^\circ$

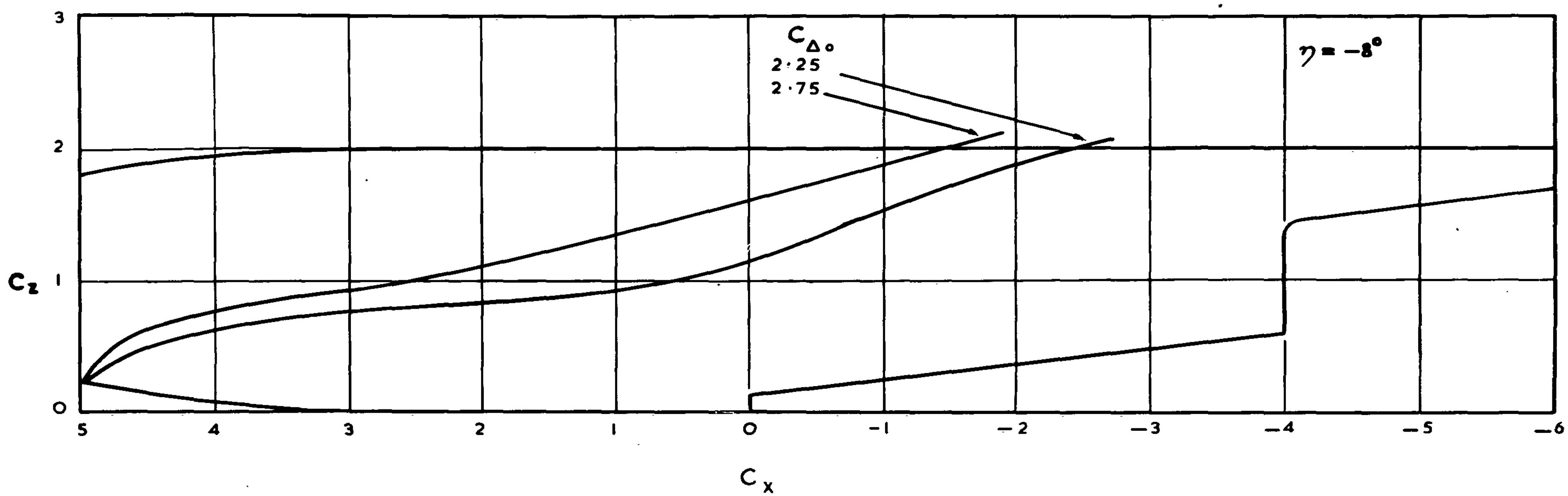
(c)
$\eta = -8^\circ$
$C_v = 9.21$
$\alpha_k = 10.2^\circ$



MODEL D
SPRAY PHOTOGRAPHS, $C_{\Delta_0} = 2.75$,(2)

FIG. 21

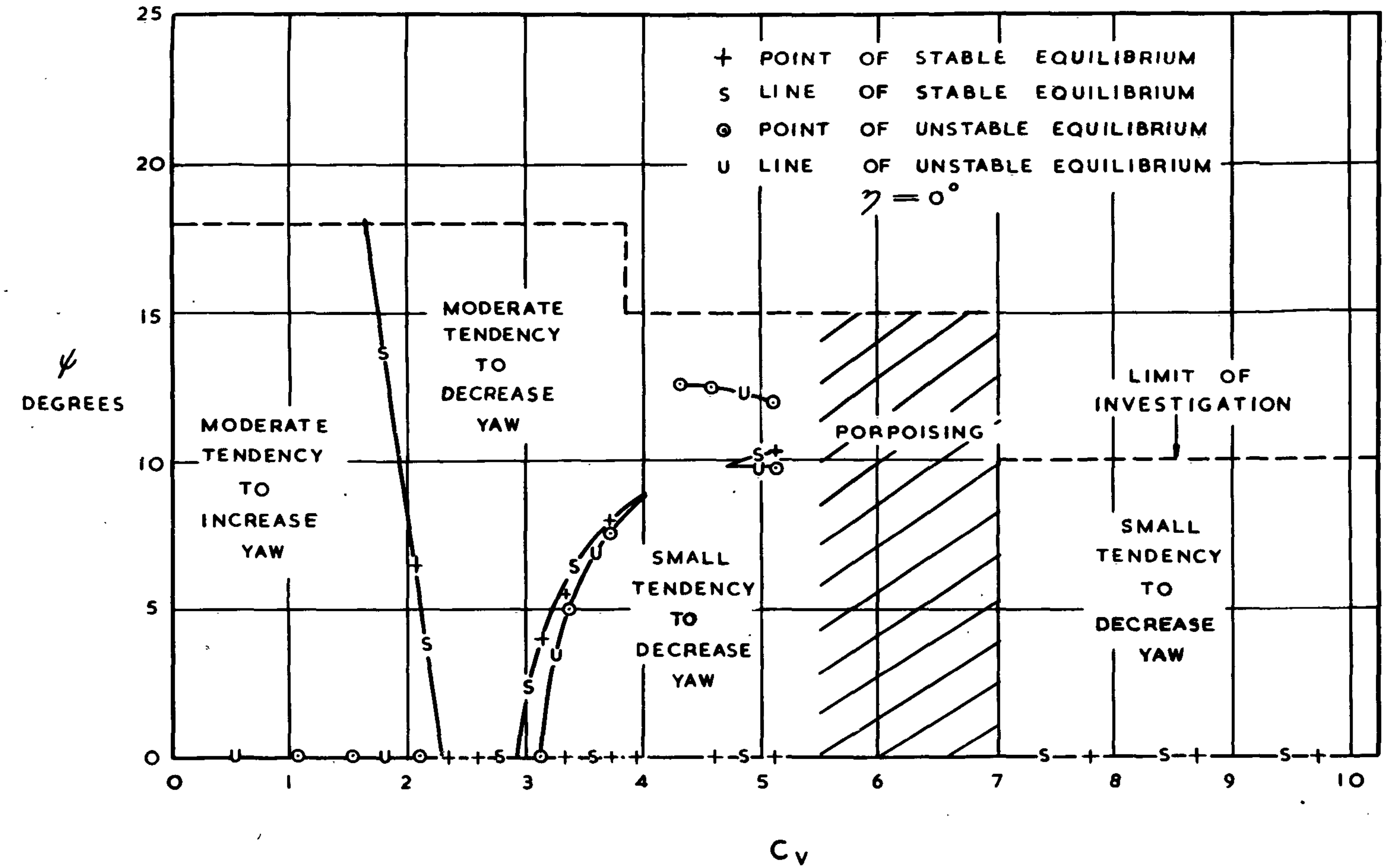
FIG. 22.



MODEL D

PROJECTIONS OF SPRAY ENVELOPES ON PLANE OF SYMMETRY OF MODEL

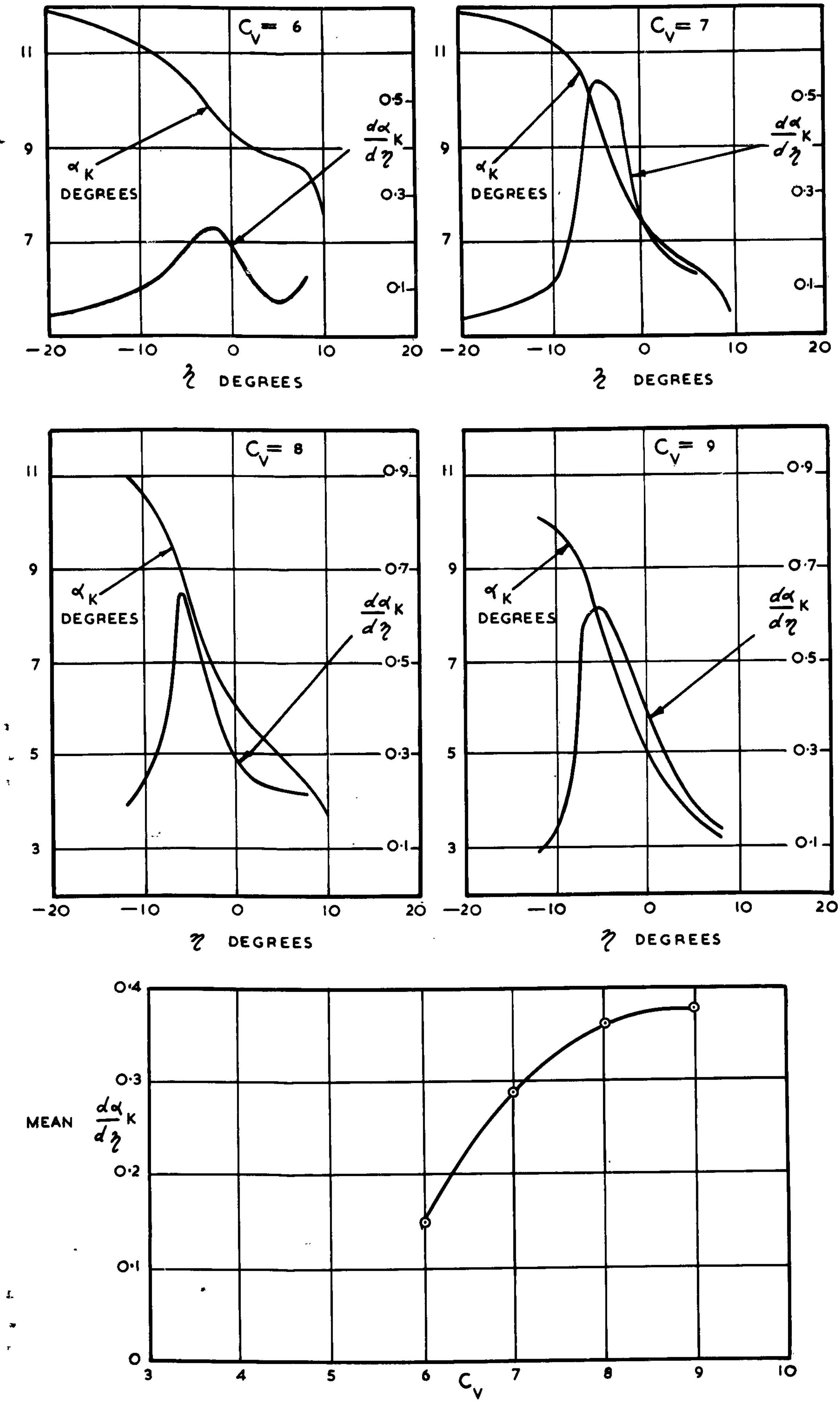
FIG. 23.



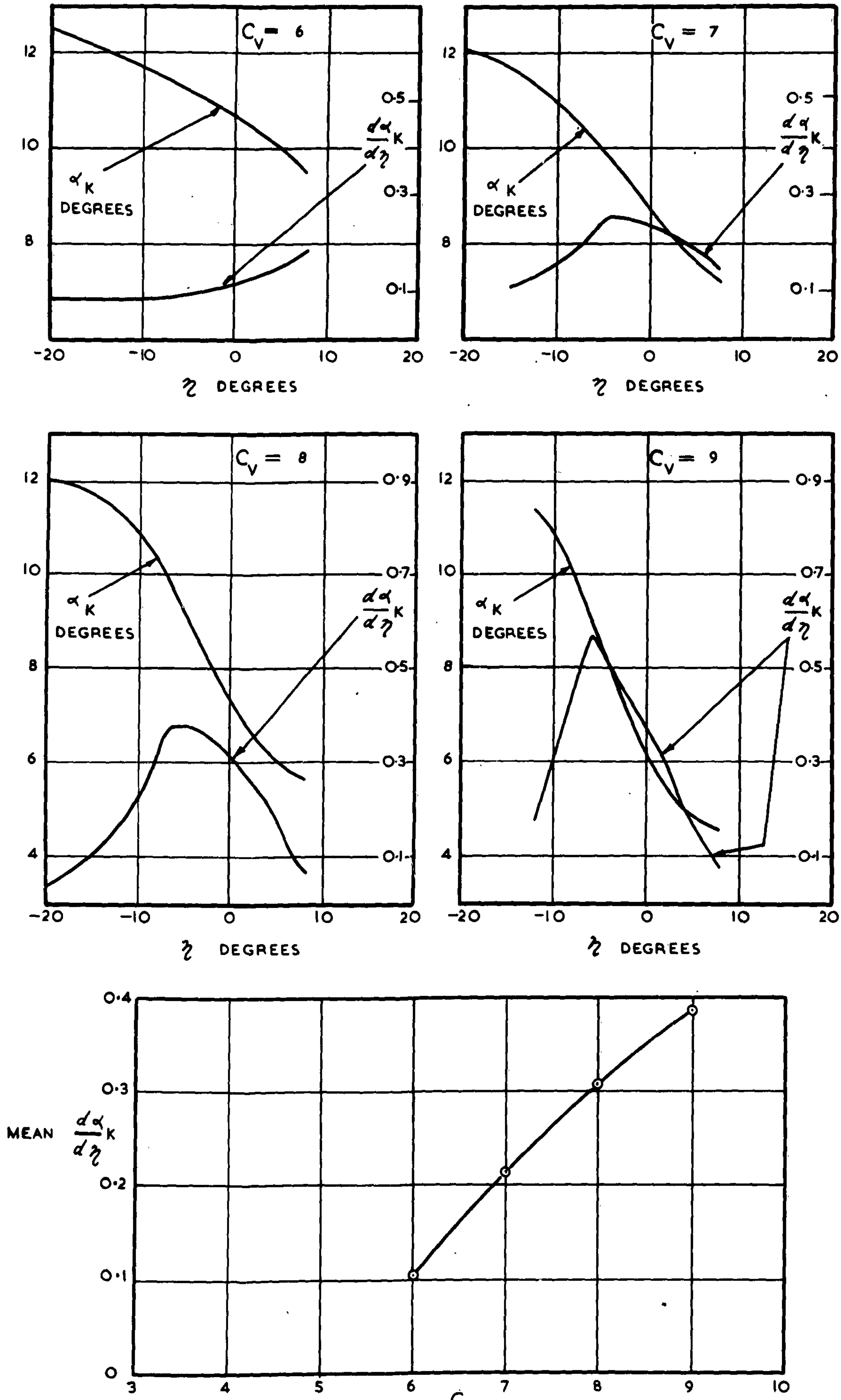
MODEL D

DIRECTIONAL STABILITY, $C_{\Delta_0} = 2 \cdot 75$.

FIG.24.



MODEL D. ELEVATOR EFFECTIVENESS, $C_{\Delta_0} = 2\cdot25$.



MODEL D. ELEVATOR EFFECTIVENESS, $C_{\Delta_0} = 2{\cdot}75$.

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